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Invasion impacts of *Acacia mearnsii* on soil properties of Shola forests in the Western Ghats

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Abstract
The Australian Black Wattle (*A. mearnsii)* introduced during the 1960s in State Forest lands located in the upper altitudes of the Palani hills, threatens native habitats by out competing indigenous vegetation for water, soil nutrients and organic matter. The present investigation was undertaken to study the soil properties of shola forests invaded by *A. mearnsii* plantations in the Western Ghats covering the Kodaikanal. Soil samples were collected from shola forests invaded by *A. mearnsii* in the Kodaikanal forest range of the Kodaikanal Forest Division. For comparison purpose, soil samples were collected from shola forest, pure *A. mearnsii* plantation, grass land and pine plantations. The soil organic carbon (5.73%) was highest under shola forest and *A. mearnsii* invaded shola forest recorded the highest available nitrogen at 0-30 cm depth (465.5 kg ha^{-1}), available phosphorus (29.8 kg ha^{-1}), exchangeable calcium (1.2 meq/100g), magnesium (1.6 meq/100g). *A. mearnsii* plantation recorded the highest available potassium (490.0 kg ha^{-1}) at 0-30 cm depth and was followed by shola forest (400.0 kg ha^{-1}), and grassland (343.0 kg ha^{-1}). The study has contributed to the understanding of soil characteristics in *A. mearnsii* invaded shola forests and the baseline data generated can be utilized for undertaking appropriate decision making in the management of forests to control the invasion menace of *A. mearnsii* thereby improving the soil quality.

Keywords: invasion, soil pH, organic carbon, shola forest

1. Introduction
The Australian Black Wattle (*A. mearnsii)* was introduced during the 1960s in State Forest lands located in the upper altitudes of the Palani hills- an eastern offshoot of the Western Ghats, a mountain range that runs parallel to the southwest coast of Peninsular India near the hill station of Kodaikanal [14, 13]. *A. mearnsii,* a small to large, evergreen, single stemmed or multi branched tree threatens native habitats by out competing indigenous vegetation for water, soil nutrients and organic matter [15]. Mass of leaf litter in areas invaded by *A. mearnsii* was reported to be greater than that of un-invaded area, thereby the dense layer inhibits the establishment of native seedlings. Between 1849 and 1992, the sholas decreased from 8600ha to 4225ha and grasslands from 29875ha to 4700ha.
Invasive plant species can modify physical or chemical attributes of soil, including inputs and cycling of nitrogen and other elements [5, 7, 8]. Nutrient dynamics may also become altered as a result of changes in the physical properties of the soil caused by the introduction of new species. Soil is the major source of nutrients for the growth of plants and determining the degree of soil physico-chemical characteristics are very necessary to evaluate the soil fertility. The nutrient transformation and its availability in soils depend on pH, clay minerals, cation and anion exchange capacity [19]. Soils exhibit difference in properties in relation to the vegetation changes and vary spatially primarily in response to rooting and litter fall characteristics of the perennial vegetation on more or less the same soil material [1].
Studies on the properties of soil in invaded shola forests are required for proper management of the forests and utilization of resources. Studies on the assessment of soil properties under shola forests invaded by *A. mearnsii* in the Western Ghats of Kodaikanal are sparse. Hence, the present study was proposed with an aim to study the soil properties of shola forests invaded by *A. mearnsii* plantations in the Western Ghats.

2. Materials and Methods
The present study was carried out in the Western Ghats of Tamil Nadu covering the Kodaikanal Range of the Kodaikanal Forest Division. Kodaikanal Forest Division lies within 10°6' and 10°21' North latitudes and 77°16' and 77°42' East longitudes and is surrounded by Kerala state in West, Indira Gandhi Wild life sanctuary, Pollachi in North-west, Dindigul forest division on the North-east and Theni revenue district in South. The altitude varies from 300 to 2654 m and this area experiences an average yearly rainfall of 165 cm. The minimum temperature of Kodaikanal varies between 8 to 13 °C and the maximum temperature varies between 11.3 to 19.8 °C.

2.1 Soil sampling and analysis
Soil samples were collected from the profile at four depths *viz.*, 0-30, 30-50, 50-80 and 80-100cm from four randomly selected plots of the shola forests invaded by *A. mearnsii* in the, Kodaikanal Forest Range. For comparison purpose, soil samples were collected from shola forest, pure *A. mearnsii* plantation, grass land and pine plantations. At each sampling point, an area of 0.5m x 0.5m was removed and a pit of 50cm wide, 50 cm in length and 100 cm deep was dug. The soil was scrapped from three sides of the pit with the help of a kurpee at each depth. The soil was mixed thoroughly and transferred to a polythene bag with proper labeling. The samples were air-dried and sieved to pass through 2 mm mesh sieve for physico-chemical analysis.

The pH of soil was determined using an aqueous suspension of soil (soil and water in 1:2.5 ratio) using a pH meter [9]. Soil organic carbon was estimated by standard Chromic acid wet oxidation method [22]. The available nitrogen in the soil was estimated by the alkaline permanganate method [21]. The concentration of available phosphorus was determined by Olsen, Bray 1 and Kurtz extraction methods [17, 2]. Available potassium was estimated by neutral normal ammonium acetate extraction [20]. The contents of exchangeable bases (Ca and Mg,) were determined by Versenate titration after extraction using 1 N ammonium acetate adjusted to pH 7.0 [3]. The data obtained were subjected to statistical analysis in SPSS ® 19.0 version statistical software. Wherever the treatment differences were found significant, the critical differences were worked out at 5 per cent probability and values were furnished. The treatment differences that are non-significant were indicated as Non-Significant (NS).

3. Results and Discussion

The effect of *A. mearnsii* invasion on soil pH in the Kodaikanal range is presented in Table 1. The soil pH varied from 5.25 to 6.15. Soil pH was highest under pine forest (6.07) at 0-30 cm depth and was on par with *A. mearnsii* invaded shola (5.85). Shola forest registered the lowest pH (5.35) at 0-30 cm depth. Similar results were reported for *L. camara* infested soils [6,18]. However, both increases and decreases in pH following plant invasion have been equally reported in the literature [5].

The concentration of soil organic carbon (SOC) in the Kodaikanal range was significantly influenced by *A. mearnsii* invasion (Fig.1). Significant differences among the study plots were observed with respect to soil organic carbon. Soil organic carbon was highest under shola forest (5.73 %) at 0-30 cm depth and was followed by *A. mearnsii* invaded shola (5.5 %), grassland (4.6%) and pine forest (4.2 %). The lowest SOC was recorded in *A. mearnsii* plantation (3.85 %). The results are concurrent with many other studies [10, 11, 4]. The combined effect of low temperature and high rainfall in shola forests restricts biochemical decomposition of organic residues in these soils and thus help maintain high organic carbon percentage, which in turn becomes responsible for the high cation exchange capacity and base saturation of these soils [1].

The available nitrogen (kg ha^{-1}) in the different study plots of Kodaikanal range is presented in Fig.2. Available nitrogen varied significantly among the study plots. *A. mearnsii* invaded shola forest recorded the highest available nitrogen (465.5 kg ha^{-1}) at 0-30 cm depth and was followed by shola forest (390.4 kg ha^{-1}), and grassland (385.1 kg ha^{-1}). The lowest available nitrogen was recorded in pine forest (152.7 kg ha^{-1}) at 0-30 cm depth. With respect to soil depth, maximum available nitrogen was registered at 0-30 cm depth. The available nitrogen showed a decreasing trend with soil depth in all the study plots of Kodaikanal range. High soil nutrients e.g. soil N concentration in *A. saligna* invaded sites compared to natural fynbos sites were reported [16, 23]. In the present study, available nitrogen, was highest under *A. mearnsii* invaded shola forest. *A. longifolia* invaded sites have high soil C and N pools than un-invaded sites in Portuguese coastal dunes [12]. The increase in available nitrogen in *A. mearnsii* invaded sites could be due to decrease in nutrient sequestration following native shola species displacement. *A. mearnsii* drops a lot of litter beneath it and this probably account for the elevated nitrogen levels when the litter decays. These findings are consistent with the findings by [5], where an increase in soil nitrate following *Lantana camara* invasion was reported.

At 0-30 cm depth, available P was highest under *A. mearnsii* invaded shola forests (29.8 kg ha^{-1}). This was followed by shola forests, pine forest, and grassland (Table 2). Available phosphorus was lowest in *A. mearnsii* plantation (25.1 kg ha^{-1}). The available potassium (kg ha^{-1}) in the different study plots of Kodaikanal range is presented in Fig.3. Significant differences among the study plots were observed with respect to available potassium. *A. mearnsii* plantation recorded the highest available potassium (490.0 kg ha^{-1}) at 0-30 cm depth and was followed by shola forest (400.0 kg ha^{-1}), and grassland (343.0 kg ha^{-1}). The lowest available potassium was recorded in pine forest (155.6 kg ha^{-1}) at 0-30 cm depth. With respect to soil depth, maximum available potassium was registered at 0-30 cm depth. The available potassium showed a decreasing trend with soil depth in *A. mearnsii* plantation, grassland and shola forest of Kodaikanal range.

The effects of *A. mearnsii* invasion on soil exchangeable calcium in the Kodaikanal range is presented in Table 3. The exchangeable calcium varied from 0.4 to 1.2. The exchangeable calcium was highest under *A. mearnsii* invaded shola forest (1.2 meq/100g) at 0-30 cm depth. This was followed by grassland (1.0 meq/100g) and shola forest (0.6 meq/100g). *A. mearnsii* plantation and pine forest registered the lowest exchangeable calcium (0.4 meq/100g) at 0-30 cm depth. The perusal of data on exchangeable magnesium in the different study plots revealed that, at 0-30 cm depth, *A. mearnsii* invaded shola forest had the highest exchangeable magnesium (1.6 meq/100g). This was found to be on par with the grassland (Fig.4). Similarly, a study on long-term invasive occupation by *Acacia longifolia* significantly altered soil properties, with increased levels of organic C, total N, and exchangeable cations [5, 12].

Table 1: Effects of *A. mearnsii* invasion on soil pH in Kodaikanal range

Study plots	Soil depth (cm)				Mean
	0-30	30-50	50-80	80-100	
A. mearnsii invaded shola	5.85	5.97	5.87	6.15	5.96
A. mearnsii plantation	5.41	5.30	5.46	5.28	5.36
Grassland	5.40	5.49	5.57	5.82	5.57
Pine forest	6.07	5.32	5.25	5.30	5.49
Shola forest	5.35	5.41	5.77	5.90	5.61
Mean	5.62	5.50	5.58	5.69	

Table 2

Factor	SE(d)	CD (0.05)
Study plots	0.13	0.26
Soil depth	0.11	NS
S x D	0.24	0.5

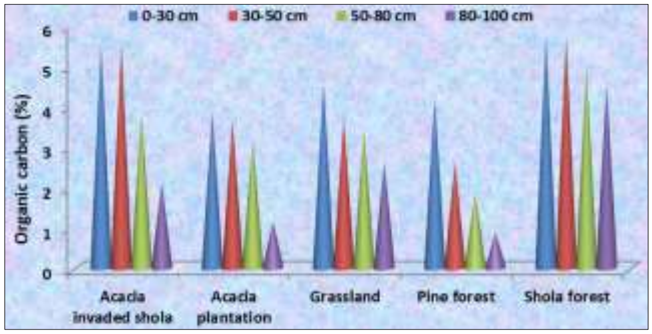

Fig 1: *A. mearnsii* invasion on soil organic carbon (%) in Kodaikanal range

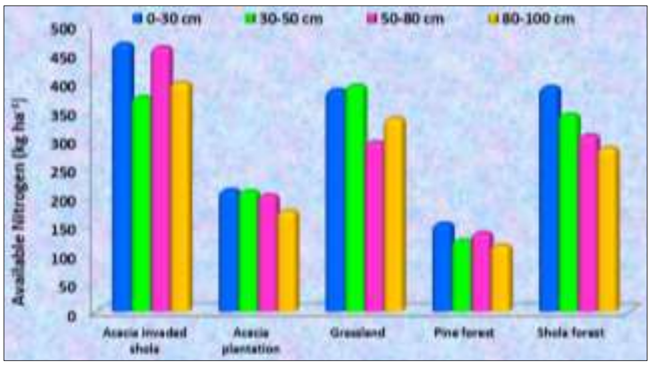

Fig 2: *A. mearnsii* invasion on available nitrogen (kg ha^{-1}) in Kodaikanal range

Table 3: Effects of *A. mearnsii* invasion on available phosphorus (kg ha^{-1}) in Kodaikanal range

Study plots	Soil depth (cm)				Mean
	0-30	30-50	50-80	80-100	
A. mearnsii invaded shola	29.8	26.3	23.7	20.8	**25.2**
A. mearnsii plantation	25.1	34.4	36.1	38.1	33.4
Grassland	25.4	31.0	24.8	25.0	26.6
Pine forest	26.0	23.7	22.5	23.9	24.0
Shola forest	27.5	25.4	22.5	27.5	25.7
Mean	26.8	28.2	25.9	27.1	

Table 4

Factor	SE(d)	CD (0.05)
Study plots	0.62	1.24
Soil depth	0.55	1.11
S x D	1.23	2.49

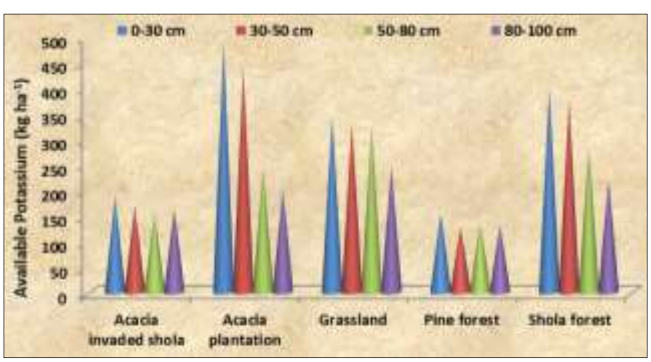

Fig 3: *A. mearnsii* invasion on available potassium (kg ha^{-1}) in Kodaikanal range

Table 5: Effects of *A. mearnsii* invasion on exchangeable calcium (meq/100g) in Kodaikanal range

Study plots	Soil depth (cm)				Mean
	0-30	30-50	50-80	80-100	
A. mearnsii invaded shola	1.2	0.8	0.6	0.6	0.80
A. mearnsii plantation	0.4	1.2	0.6	0.6	0.70
Grassland	1.0	0.8	0.6	0.6	0.75
Pine forest	0.4	0.4	0.8	0.6	0.55
Shola forest	0.6	0.8	0.4	0.8	0.65
Mean	0.72	0.8	0.6	0.64	

Table 6

Factor	SE(d)	CD (0.05)
Study plots	0.02	0.04
Soil depth	0.01	0.03
S x D	0.04	0.08

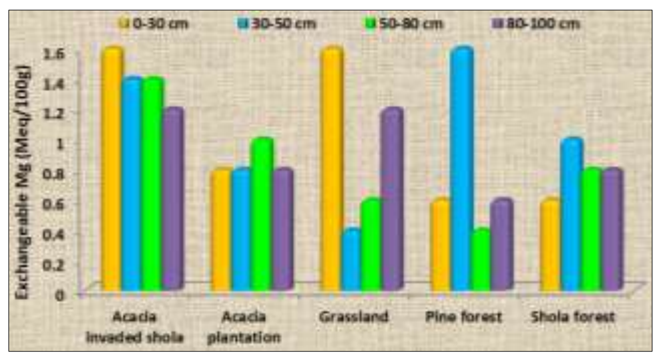

Fig 4: *A. mearnsii* invasion on exchangeable magnesium (meq/100g) in Kodaikanal range

4. Conclusion

Studies on the nature and properties of soil in invaded forest ecosystems are important for proper management of the environment and utilization of resources. Without adequate knowledge of the dynamic interaction between soil, climate and forest management we cannot develop a proper soil management system. Soil properties such as pH, available nitrogen, available phosphorus, available potassium, exchangeable calcium and magnesium in the soil varied significantly under *A. mearnsii* invaded shola forests compared with native vegetation. The findings explain the ability of *A. mearnsii* to outcompete the native species. Baseline data generated in the present study can be utilized by the State Forest Department for undertaking appropriate decision making in the eco-restoration of areas invaded by *A. mearnsii*.

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