Possible role of the soil in the sissoo forest (*Dalbergia sissoo* Roxb.) decline in the Nepal terai

S.P. Sah[1], C.K. Sharma[1], F. Sehested[2]

[1]*Department of Biological and Environmental Sciences, Kathmandu University, Dhulikhel, Kavre, Nepal*
[2]*Danish Forestry Extension, Koteshwor, Kathmandu, Nepal*

ABSTRACT

This paper deals with the recent sissoo (*Dalbergia sissoo* Roxb.) decline in the plain land (locally called as terai) of Nepal. This study has made an attempt to find the possible causal factor of this decline. The study has made some initiative in this aspect and has made a comparative study of 30 different sissoo forest (both natural and plantation) stands. The symptoms of the sissoo decline were found to be varied. But in most of cases, the top dying of crown was found to be the most prevalent. The top dying starts from the top of the tree and progressively proceeds downwards to the stem. The leaves become yellow. Until now, it has been assumed that only the plantation forests have been affected but this study observed the sissoo decline also in natural forest sites. We analysed various components of physical soil characteristics and we did not find any correlation between the physical soil factors and the sissoo decline. We concluded from this study that the soil is not the sole responsible factor involved in the sissoo decline Furthermore, this paper discusses various aspects of the sissoo decline and possible causal factors concerned. Finally, future management strategies regarding the sissoo management are suggested.

Keywords: sissoo forest; *Dalbergia sissoo* Roxb.; soils; pathogens

The accelerated rate of deforestation in Nepal in the past has resulted in severe forest degradation in the country. Fortunately, the fast growing tree species present in the country have become very popular for their plantation to overcome this problem. One of the fast growing tree species is sissoo (*Dalbergia sissoo* Roxb.). Sissoo is a nitrogen-fixing leguminous multipurpose tree species occurring in the lowland region of Nepal (locally known as terai) up to an altitude of 1000 m. It is an important reforestation species on the lowland. This plant species occurs naturally in the riverain sal forest (*Shorea robusta* Gaertn.). It thrives well in the sandy-loam soil with good drainage. This species, due to its fast growth, quality timber, easy propagation, and drought resistance has been the most favourable plantation species on the private as well as government level for the last three decades. Due to its popularity, local communities have planted this species everywhere, such as agricultural fields, canal sides, pond banks, wastelands, etc. Due to a short rotation of timber harvesting of the sissoo, the profit from the plantation of this trees species in the past was so much bigger in comparison with that from the agricultural products that people preferred to go ahead for the sissoo plantation rather than agricultural crops. Unfortunately, for the last three-four years, this tree species has been dying in the plantation forests. The plantation sites, ranging from one-year-old to matured trees, are affected with a decline. However, their status in the natural forests is still unknown. The sissoo decline has become so serious that people are now afraid of further plantation of this species. The extent of sissoo mortality in natural forests or in plantation forests has not been enumerated so far. This study has made an attempt in this direction. A similar decline phenomenon has been reported from the adjoining boarder area of India in Bihar and Utter Pradesh (Sharma et al. 2000) as well as from other Indian sub-continent nations.

As concerns of Nepal, no definite reasons for such decline have been recognized until now. Sissoo was found infected by a fungus *Fusarium oxysporum* on waterlogged soils (Karki 1992, Parajuli et al. 1999). Beetles were also noticed to cause heavy losses of young leaves of this plant species (Amatya 1994). Untill now, only pathological researches have been focused on the sissoo decline. The question arises, what may be the reason behind such dieback? Are only pathological factors the cause of the Sissoo decline? However, Manion (1981) suggested that, in a forest decline, the primary cause should be some abiotic environmental factors rather than pathological ones. He elucidated the relationship between different stress factors and the forest decline and distinguished three groups of stress: A. Predisposing stress: a long-term factor, relatively static and nonchanging such as climate, soil, genetic potential, tree ageing, long-term air pollutants. It puts a permanent stress on the plant and weakens it so that other factors may become effective. B. Inciting factors: a short-duration factor, which may be abiotic or biotic; examples are

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insect defoliators, frost, drought, short-term effects of high air pollutants concentration etc. C. Contributing stress: this is the final factor of decline killing the plants. Examples are bark beetles, cancer fungi, root and sap root fungi, viruses etc. producing definite symptoms of disease. No significant research has been done so far on the abiotic components. The first attempt in this direction was the study of Sah et al. (1999) who reported the soil factor to be the main reason behind the decline in a sissoo plantation forest of Sauraha, Chitwan, Nepal.

As mentioned above, the sissoo decline may be associated with many factors but this study has mainly been limited to the physical soil characteristics of sissoo stands. The reason for such a selection of this soil parameter is that the physical properties of soils (such as moisture content, soil colour, soil density, soil porosity etc.) reflect the basic site characteristics such as the availability of oxygen in soil, mobility of water into or through soil, the ease of root penetration etc. For this purpose, this study has been focused on 30 research stands in the terai from Central Development Region to Eastern Development Region. The objective of this paper is to compare the stand characteristics of the different sissoo stands, involving both natural and plantation sites.

MATERIAL AND METHODS

Research site

The kingdom of Nepal occupies a large part of the central Himalayan and its foothills. Topographically, Nepal can mainly be divided into three parallel zones: i. Plain land/terai (up to the altitude of 200 m), terai is the name (in Nepali language) given to plain land consisting of alluvial deposition, ii. Middle Hills (up to 3500 m), iii. The high Himalayas (up to 8848 m).

The climate of terai is subtropical to tropical, mainly exposed to the influence of the Monsoon climate. Summers are hot with a temperature range of 15–40°C. Maximum precipitation rates are observed between June and September with the annual average of 1300–2600 mm. On the contrary, the winter months (November to April) are very dry. The terai's relatively favourable topographical, climatic and soil conditions account for its high agricultural potential and its function as the country's bread basket.

The forest cover of the terai is estimated to be 475 000 ha (8.6% of the total Nepal's Forests). Sal forest (*Shorea robusta* Gaertn.) is the dominant forest in the terai and in the lower hill region. Sal is a commercially valuable timber species in the whole country. Forests along the rivers comprise mainly sissoo (*Dalbergia sissoo* Roxb.) and Khair (*Acacia catechu* Willd.) which are the next important tree species for the timber and fuelwood production. Sissoo grows in light and open stands with an average height of 25–30 m. This shows why the sissoo species, which is economically the second species, was greatly exploited in the past. This study has been limited, however, only to the terai region from Central Development Region to Eastern Development Region (Figure 1).

Reconnaissance survey and site selection

The 30 research sites (both natural and plantation sites) have been selected in the lowland of Nepal from Central Development Region (Hetauda) to the Eastern Development Region (Jhapa district) for the present study on the basis of the reconnaissance survey. Both healthy and

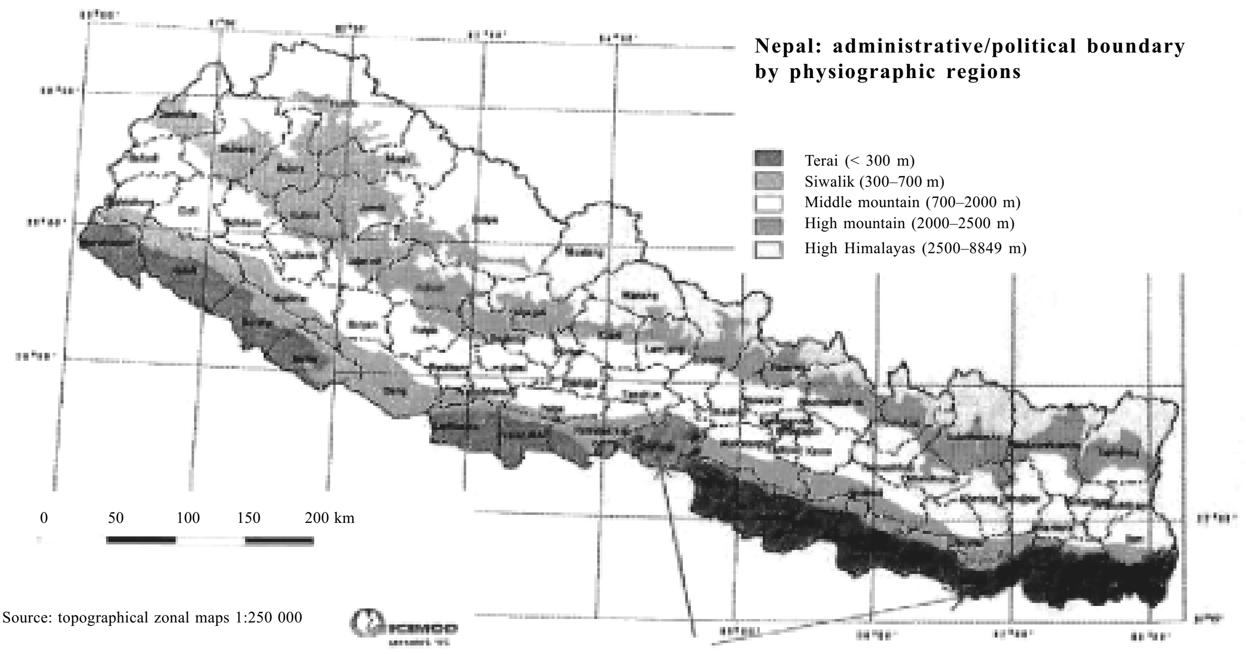

Figure 1. Map of Nepal showing the study areas in the terai (administrative/political boundary by physiographic regions)

diseased plantation sites have been selected for this purpose. After the survey, two natural sissoo sites and 28 plantation sites were selected in the above mentioned regions of terai. The natural stands of sissoo have greatly been degraded and only two matured natural sissoo stands could be found. No completely healthy sissoo plantation could be found. All these selected sites were the subjects of the following studies:

Plantation profile data collection

For the plantation forests, the past information on their plantation techniques and the present state of sissoo stands was collected through the information given by forest-owners. In the case of natural sissoo stands, similar information was collected from the local people. Furthermore, the height and diameter of all the sites were estimated through the Quadrate method (25 m × 25 m). One quadrate was laid out in each stand and the different stand parameters were studied. From the visual observation as well as the information given from the forest owners, the stands were categorised for their different mortality status. Based on the mortality status of the sites, all stands were categorised into: i. healthy site (all trees healthy), ii. low mortality (less than 10% mortality), iii. moderate mortality (10–30%), iv. high mortality (more than 30%).

The forest owners had pruned the sissoo trees, almost on all plantation research sites, in the past. Therefore, it was not possible to evaluate the defoliation status of most of the plantation sites. The mortality status of such sites was principally assessed through the information given by the forest owners. In the case of natural stands, this was studied by the standard Quadrate method (as mentioned above). To know the root distribution pattern of the trees, the soil from the rooting zone was excavated and the fine root zone was exposed. Then, the fine root samples were taken. After this, the depth of the fine root system in the soil was recorded.

Soil samples collection and analysis

There were no significant humus layers on any of the studied sites. Therefore, no humus sampling was possible. Only the mineral soil sampling was done. For this purpose, five soil samples were collected from each plot in a systematic way (5 dots on a dice) and all samples were analysed in the laboratory. The soil sampling was done from the topsoil (mineral soil layer) and sub-soil layers. The top- and sub-soil layers were chiefly from the depth of 0–20 cm and 20–50 cm, respectively, in the study areas. The extraction of soil samples was carried out by iron soil-auger from the above mentioned soil depths. Altogether 150 soil samples (30 stands × 5 samples) were collected. After collection of the soil samples, each sample was labelled and its fresh weight was taken directly in the field. The soil physical characteristics such as soil colour (Munsell's colour Charts), soil texture (Sieve method), water holding capacity, soil moisture, soil density, and soil porosity were determined in each sample by standard methods. In addition, soil pH was also determined by the standard pH Electrode method.

RESULTS AND DISCUSSION

Sissoo forest stands profile and their characteristics

Based on the primary as well as the secondary information, the sissoo plantation profile is illustrated in Table 1. From this table, it is evident that the present investigation involves different kinds of sissoo forests, from a small scale (0.5 ha) to a large scale (more than 500 ha) plantation, natural to plantation forest, young plantation (4-year-old) to older plantation (28-year-old sites) etc. The height of the trees on all sites varied from 6 m (Rani Sikiyahi) to 32 m (Surunga) and the diameter ranged from 4 cm (Rani Sikiyahi) to 30 cm (Sissoodhari and Surunga).

Furthermore, the mortality status on all sites ranged from healthy to high mortality stands. Only one stand Sissoodhari, which is a natural sissoo stand, was found healthy while all other plantation and natural (Surunga) forests showed decline symptoms, ranging from a low mortality (Surunga, Chuchche Khola, Sauraha, Baghmara, Pushapalpur, Lalbhitti, Jatuwa, Janpath-west, Ghinaha Ghat, Duhabi and Aurabari) to a high mortality (Tilkane, Jatuwa-SC, Belgachhi, Dhanusha-1 and Lakhanpur) stands. All sites varied from well-drained (such as healthy site, the majority of low mortality sites and moderate mortality sites) to water-logged soils (all the stands with a high mortality and a few stands of both the low mortality and the moderate mortality status such as Chuchche Khola, Sauraha, Ram Nagar, Mrigauli, Top Gachhi, Dharampur etc.). The fine root mass was found mostly in between 0–50 cm soil depth in the majority of the sites.

Visible symptoms of the decline

Symptoms of the sissoo decline were varied. But in most cases, the top dying of crown is the most prevalent. The top dying starts from the top of the tree and proceeds progressively downwards to the stem. The leaves turn yellow. This was the general visual symptom in the majority of the declining stands. However, in addition to the above mentioned symptoms, the declining trees showed also the following types of damage: i. defoliation by the insect borer, ii. oozing of black or black reddish sap out of the stem, iii. stem covered with termites up to a certain height, iv. the infection of the leaves with certain fungi.

In most of the plantation sites, the visual symptom of the sissoo disease was black to black-reddish sap oozing out of the stem. However, at some plantation sites, the diseased trees did not ooze out such sap at all but the tree still started dying from the top. Sissoo trees of varying age (from younger to older plantations) were dying. However, the majority of the young plantations

Table 1. Forest profiles of all plots

Name of site	N/P	District	Hills/ terai	Habitat	Area (ha)	Age (years)	Height (m)	Diameter (cm)	Mortality	Fine root zone	Water drainage
1. Sissoodhari, Hetauda	N	Makwanpur	hills	Riverain	–		31	30	healthy	0–50	very good
2. Surunga:	N	Jhapa	terai	Riverain	–		32	25	very low	0–50	good
3. Chuchche Khola	P	Makwanpur	hills	Riverain	2.04	9	12	12	very low	0–50	water-logged
4. Sauraha	P	Chitwan	terai	Riverain	2.30	5	11	11	very low	0–50	water-logged
5. Baghamara	P	Chitwan	terai	riverain	400.0	10	8	12	very low	0–50	good
6. Pushapalpur	P	Dhanusha	terai	Riverain	1.36	4	11	8	very low	0–50	good
7. Lalbhitti	P	Dhanusha	terai	Riverain	2.04	8	10	8	very low	0–50	good
8. Jatuwa	P	Morang	terai	field	12.24	5	11	13	very low	0–50	water-logged
9. Janpath-East	P	Morang	terai	field	3.4	8	11	8	very low	0–50	good
10. Ghinaha Ghat	P	Morang	terai	field	3.40	10	21	26	very low	0–50	good
11. Duhabi	P	Sunsari	terai	Urban	2.04	6	21	24		0–50	good
12. Aurabari	P	Sunsari	terai	Riverain	2.04	7	16	11		0–50	good
13. Churia Mai	P	Makwanpur	Hills	riverain	1.75	12	25	21	moderate high	0–50	good
14. Ram Nagar	P	Mahotari	terai	field	0.34	22	14	10	moderate high	0–50	water-logged
15. Dhanusha-2	P	Dhanusha	terai	field	544.00	15	26	26	moderate high	0–50	good
16. Janpath (west)	P	Morang	terai	field	4.08	5	9	10	moderate high	0–50	good
17. Rani Sikiyahi	P	Morang	terai	field	3.00	4	6	4	moderate high	0–50	good
18. Katahari	P	Morang	terai	field	0.68	5	9	9	moderate high	0–50	good
19. Pokariya	P	Morang	terai	Riverain	1.36	8	18	12	moderate high	0–50	good
20. Mrigauli	P	Morang	terai	field	8.16	15	26	28	moderate high	0–50	water-logged
21. Dandi Ghat	P	Morang	terai	field	136.00	5	11	11	moderate high	0–50	good
22. Bhokra	P	Sunsari	terai	field	22.10	17	22	23	moderate high	0–50	good
23. Satashi Dham	P	Jhapa	terai	field	408.00	18	21	21	moderate high	0–50	water-logged
24. Top Gachhi	P	Jhapa	terai	field	340.00	20	22	29	moderate high	0–50	water-logged
25. Dharampur	P	Jhapa	terai	field	340.00	16	18	12	moderate high	0–50	water-logged
26. Tlkane	P	Chitwan	terai	field	3.0	7	10	10	very high	0–50	water-logged
27 Dhanusha-1	P	Dhanusha	terai	field	544.00	15	26	29	very high	0–50	water-logged
28. Jatuwa-SC	P	Morang	terai	field	4.08	8	12	8	very high	0–50	water-logged
29. Belgachhi	P	Mahotari	terai	Riverside	10.2	14	15	13	very high	0–50	water-logged
30. Lakhanpur	P	Jhapa	terai	field	544.00	18	17	26	very high	0–50	water-logged

N = natural, P = plantation

(such as Sauraha, Pushapalpur, Lalbhitti, and Janpath-west) were less affected as compared to the older plantations (Belgachhi, Lakhanpur, Dhanusha-1, Bhokra etc.). Amatya (1994) also reported heavy loss of young leaves of this plant species attacked by the beetles. Similar results were also reported by Parajuli et al. (1999). They reported the presence of fungi such as *Fusarium* sp. and *Gandoderma lucidium* in the roots and stems of the diseased trees of sissoo from Nepal. Similar root disease was reported from N.E. Indian provinces such as Bihar and Uttar Pradesh in the sissoo grown on clayey soil under water-logging conditions (Bakshi and Singh 1959).

Physical characteristics of the soil in different sites

All the physical characteristics of soil and soil pH are summarised in Table 2. This table shows that the soil pH, in general, varies from highly acidic (pH 4.8) at the site Surunga (natural forest) to highly alkaline (pH 7.9) at the sites Baghmara, Belgachhi, Janpath-west, Pokharia and Duhabi. The growth of trees on all the above mentioned sites was moderately good, except in the case of Belgachhi (a high mortality stand). It appears that sissoo can survive well in the wide range of soil pH. In the healthy stand of Sissoodhari, the soil pH was found to be highly basic (pH = 7.5) in all soil depths (0–50 cm depth). But in most of the plantation forests, pH ranged from 5 to 6 (the usual range of soil pH suitable for most of the plant species). All the high mortality stands (except Belgachhi) such as Jatuwa Science Campus, Tilkane, Dhanusha Dham-1, Lakhanpur have the above mentioned pH range. In addition, the stands with low to moderate mortality have also a similar pH range. Therefore, we believe that soil pH does not have any tendency with respect to the decline of sissoo. Similar pH range (even with a higher pH value up to 8.5) was reported from the sissoo forests of Bihar and U.P. of India (Sharma et al. 2000). As expected, in the majority of stands, pH values increased with the increasing depth of soils which is attributed to the increased acidity in the top-soil due to the accumulation of organic acids produced by organic matters.

Soil colours in most of the stands are grey and brown. However, in some cases, black colour has also been observed in the top-soil layer (such as Tilkane and Churia Mai). Black colour of soil indicates a higher humus content in the soil, holding more water. At the same stands, a mottle of rust colours was also observed from the top to sub-soil layers, and this indicates the previous water accumulation in the soil. Such water-logging of the soil has been observed in all excessively dying stands. Other stands such as the low mortality (see above) and the moderate high mortality stands, e.g. Satashi Dham, Top Gachhi and Dharampur, also showed water-logging.

Soil density varied from 0.94 to 1.63 g/cm^3 at all the stands studied, and the soil porosity from 65–39% accordingly. The lowest density values (i.e. the highest porosity) of soil was recorded at the stands of Pokhariya, Satashi Dham (moderate mortality), and Lakhanpur (high mortality), and this is supported by the occurrence of a higher clay content (or high organic matter) in the soil. Opposite is true for other plots with sandy soils.

In the present study, the stands on sandy soil had the pore space less than 50% thus indicating their good suitability for the plant growth. But in most of the stands on clayey soil, the soil porosity was lower than 50% showing unsuitability of the soil for a proper growth of plants.

The sub-soil on the majority of the sites, both healthy and diseased, as expected, is loosely-textured soil. However, in some cases, such as Baghmara, Jatuwa, Janapath-west, Rani Sikiyahi, Katahari, Bhokra (moderate mortality) and in Jatuwa Science Campus (high mortality), the sub-soil is heavily-textured (Table 2). This means that there is again no direct relation between the sub-soil characteristics and the sissoo decline. The water logging was not observed in the above mentioned stands except in the Jatuwa Science Campus stand. Thus, the sissoo stands were found to decline on the sites having almost all types of the soil texture. Even the high mortality stands also vary with regard to their texture. For example, on sandy soils too, the forests were found to die severely as in Tilkane, Lakhanpur and Belgachhi, but having water logging. At Tilkane, the soil, although sandy, contains a lot of organic matter, which is reflected in its black colour. But in Lakhanpur and Belgachhi, in spite of their sandy soils, there is a severe occurrence of water logging. Furthermore, the stands having clayey soil both in top and sub-soil layers (such as Dhanusha Dham-1 and Jatuwa Science Campus), are also declining. In the natural site of Surunga, the soil texture was found sandy having no water logging, but also declining. This means that the soil texture alone cannot be responsible for the decline of the sissoo on those sites.

Physical characteristics of soil and its overall relation to the sissoo decline

The primary causal factors involved in the root infection by *Fusarium* sp. is mostly assigned to the absence of O_2 in the root zone due to the prolonged water condition, especially in the rainy season when the water table rises and can ascend up to the tap root (Bakshi et al. 1976). It has been reported that water table may rise up to the depth of only 2–3 meters of soil surface in the terai, and the tap root may come in contact with the water table and become more susceptible to the above mentioned fungus. The experience that sissoo thrives well on the loosely-textured soils but suffers adversely from the root disease in the stiff clayey-soil has been widely accepted. The success of the species on the loosely-textured soil appears to be due to the proper soil aeration and the good drainage which leads to the healthy growth of roots (Bagchee 1945, Bakshi 1954, 1957). Recently, the study of Sah et al. (2002) concluded that the water logging is the main responsible factor involved in the decline of sissoo stand at the Tilkane site of Nepal. Therefore, based on these studies, it can be assumed that only the loosely textured soils with good drainage are suitable for proper sissoo trees growth.

However, in the present study, at least in the event of sissoo decline, the above mentioned mechanism does not seem to apply fully. In the present study, it has been found that there is no definite relation between the soil texture and the intensity of sissoo mortality. The trees in the high mortality stands (Belgachhi, Jatuwa Science Campus, Dhanusha Dham-1, Lakahnpuir and Tilkane) were found to grow both on the loosely textured and the heavily-textured soils. However, the water-logging is prominent in all of these stands. But in other stands (both low mortality and moderate mortality), the sissoo decline was observed equally on the water-logged soil and well-drained soil. Furthermore, the stands with low mortality (Sauraha, Jatuwa, Chuchche Khola) are also water-logged. Above all, the natural stand of Surunga has sandy soil with no water logging but it suffers from slight top dying. Therefore, this study does not allow us to believe very easily that the clayey soil texture with the water-logging is the sole responsible causal factor involved in the decline.

In the high mortality stand of Tilkane, the soil is black in colour and the texture is sandy. The black colour indicates the occurrence of a higher amount of organic matter in the soil leading to a high moisture availability. But due to the occurrence of water-logging at this stand, most of the sissoo tree leaves were infected by the fungus. But at the stand of Churia Mai (moderate mortality), the soil is almost black but the tree leaves are more or less healthy because this stand is situated on a small hill which results in a proper drainage of the accumulating water. In this case, the water drainage seems to have played a role but both stand, however, are dying. They only differ in their symptoms. Tilkane shows a heavy infection of trees leaves, whereas Churia Mai shows typical oozing of dark reddish sap out of the bark. Therefore, this study leads us to conclude again that water logging may have played some role in the sissoo decline but not as the sole responsible causal factor.

The healthy stand of Sissoodhari, which is reverain in habitat, has loosely-textured soil with a good drainage.

Table 2. Declining status of different plots and their soil characteristics

Forest sites	Soil pH		WHC (%)		Soil-texture		Soil density	Soil porosity	Soil colour	
	top-soil	sub-soil	top-soil	sub-soil	top-soil	sub-soil	(g/cm^3)	(%)	top-soil	sub-soil
A. Healthy stands										
1. Sissoodhari, Hetauda	7.54	7.37	60	40	loamy	SL	1.43	46	2.5Y4/2	10Y3/2
B. Stands with low mortality										
1. Surunga	4.38	5.54	70	33	sandy	dandy	1.34	49	10YR4/2	10YR6/2
2. Chuchche Khola	5.02	5.91	50	50	clayey	SL	1.45	45	10YR6/2	2.5Y7/3
3. Sauraha	4.97	5.23	47	40	clayey	SiL	1.63	39	10YR4/2	10YR5/4
4. Baghamara	7.38	7.58	70	45	sc	CL	–	40	10YR4/2	10YR6/2
5. Pushapalpur	5.78	6.16	30	35	sl	SL	1.56	41	2.5Y6/2	2.5Y6/2
6. Lalbhitti	5.46	6.02	50	40	sl	SL	1.42	46	2.5Y6/2	2.5Y6/2
7. Jatuwa	5.47	5.61	50	46	sl	clayey	1.55	42	2.5Y6/3	2.5Y6/2
8. Janpath-East	5.33	6.50	60	50	clayey	SL	1.30	51	2.5Y6/3	2.5Y7/3
9. Ghinaha Ghat	5.22	5.22	60	50	sil	SiL	1.60	40	2.5Y6/3	2.5Y6/3
10. Duhabi	7.47	7.84	50	50	clayey	SCL	1.36	49	2.5Y6/2	2.5Y6/3
11. Aurabari	5.10	6.48	80	67	clayey	SL	1.47	45	2.5Y6/3	2.5Y5/2
C. Stands with moderate mortality										
1. Churia Mai	6.46	5.32	50	40	SL	SL		39	7.5YR2.5/2	10YR4/4
2. Ram Nagar	6.39	6.56	40	30	SL	SL	1.43	46	2.5Y5/2	2.5Y6/2
3. Dhanusha-2	6.29	6.61	45	40	clayey	SL	1.34	49	2.5Y5/2	2.5Y7/3
4. Janpath (west)	7.8	7.97	60	70	clayey	clayey	1.45	45	2.5Y6/2	2.5Y6/2
5. Rani Sikiyahi	6.01	5.37	60	60	clayey	clayey	1.44	48	2.5Y7/2	2.5Y7/3
6. Katahari	5.61	6.76	60	60	clayey	CL	1.44	46	2.5Y5/2	2.5Y6/2
7. Pokariya	7.27	5.54	60	60	CL	SL	0.94	65	2.5Y5/3	2.5Y5/3
8. Mrigauli	5.73	6.40	50	60	SL	sandy	1.42	49	2.5Y6/2	2.5Y6/2
9. Dandi Ghat	5.91	6.55	50	56	SL	sandy	1.36	49	2.5Y5/2	2.5Y6/2
10. Bhokra	5.11	5.25	50	67	SL	clayey	1.55	42	2.5Y3/2	2.5Y6/2
11. Satashi Dham	5.40	5.66	60	60	SL	SC	1.25	53	2.5Y5/2	2.5Y6/2
12. Top Gachhi	6.71	5.50	50	46	clayey	sandy	1.38	48	2.5Y6/2	2.5Y5/2
13. Dharampur	6.17	6.41	50	50	SC	SL	1.48	44	2.5Y5/2	2.5Y7/2
D. Stands with high mortality										
1. Tlkane	6.01	5.45	50	55	SL	SL	1.40	47	7.5YR2.5/1	7.5YR2.5/1
2. Dhanusha-1	6.23	6.32	50	50	clayey	CL	1.55	42	2.5Y7/3	2.5Y7/3
3. Jatuwa-SC	5.11	5.70	60	70	CL	C	1.51	43	2.5Y6/3	2.5Y6/3
4. Belgachhi	7.10	7.50	40	30	SC	sandy	1.49	44	2.5Y6/2	2.5Y6/2
5. Lakhanpur	4.99	5.27	40	40	sandy	sandy	1.16	56	2.5Y6/3	2.5Y6/3

SC = sandy-clay, SL = sandy-loam, CL = clayey-loam, SCL = sandy-clay-loam, SiL = silty-loam, WHC = water holding capacity

2.5Y4/2 = dark greyish brown, 2.5Y3/2 = very dark greyish brown, 10YR5/4 = yellowish brown, 2.5Y6/3 = light yellowish brown, 2.5Y6/2 = light brownish grey, 10YR6/2 = light brownish gray, 2.5Y7/2 = light grey, 2.5Y5/2 = grey brown, 10YR4/4 = brown, 2.5Y5/3 = light olive brown, 2.5Y7/3 = pale yellow, 10YR4/2 = dark grey brown, 2.5Y7/2 = light grey, 2.5Y7/4 = pale yellow, 10YR3/2 = very dark greyish brown, 2.5Y6/4 = light yellowish brown, 7.5YR2.5/2 = very dark brown, 7.5YR2.5/1 = black

Soil density and porosity are also suitable for the sissoo growth. This stand was found fully healthy. But this fact is not sufficient for the explanation of the decline either because many declining sissoo stands (from low mortality to high mortality stands) are situated on the riverside having sandy soils with no water logging. Another natural stand Surunga also suffers from typical top dying (with low mortality status). This stand differs from Sissoodhari in that it is not directly situated on the riverside but the other soil characteristics are almost similar to Sissodhari. In the context of the water-logging status of different stands, it was found that the healthy stands, as well as stands with low mortality to moderate mortality, have in a majority of cases good water drainage (except in Jatuwa, Chuchche Khola, Ram Nagar, Mrigauli, Top Gachhi and Dharampur) but they have a varied range of the soil texture, both sandy and clayey. Therefore, as mentioned above, water-logging alone cannot be considered as a prominent causal factor involved in the sissoo decline. In the Indian sissoo decline studies (Bihar and UP), similar results were recorded and the sissoo was found dying on all types of soils (Sharma et al. 2000).

CONCLUSIONS

Summary of findings

The stands selected in this study have a wide range of variations such as young (4-year old) to older (28-year old) plantation, natural to plantation sites, healthy to high mortality stands etc. From the study of all these stands, the following inferences have been made:

Out of the total 30 stands, a majority of the stands (29 stands) were more or less dying. The decline was from low mortality to high mortality. Only the Sissoodhari stand, which was natural, was fully healthy. Another natural site (Surunga) also showed a low decline trend. Out of 30 stands, 5 stands (Tilkane, Jatuwa-SC, Belgachhi, Dhanusha-1, and Lakhanpur) were dying excessively.

No relationship between pH of soil and the stand mortality was ascertained. The pH of different habitat soils ranged from highly acidic (4.5) to high alkaline (8.0). The stands were dying on all types of soils, varying from highly acidic to highly alkaline.

Similar to pH, Water Holding Capacity (WHC) did not follow any definite pattern in relation to the declining status of different sissoo stands. WHC ranged from 30–70% and the soil moisture content from 10–25%.

Soil density of the individual stands varied from 0.94 g/cm^3 to 1.63 g/cm^3 and the soil porosity percentage from 65% to 39% accordingly. The healthy stand of Sissoodhari had the soil density of 1.43 g/cm^3 (Sandy soil). As expected, the lowest density values were found in the case of stands on heavily-textured soils, and opposite was true for the stands on loosely-textured soils. The high mortality stands did not, however, show any trend in density and porosity with respect to their dying status.

Soil of the top-soil in the majority of the sites was heavily-textured and sub-soil loosely-textured. The stands were observed to die on all types of the soil texture. No definite trend existed between the soil texture and the stand mortality. Sissoo dieback was much more prominent in the stands on stiff clay and water-logged soils.

Water logging was found to intensify the decline. There was no correlation between the stand mortality and the water drainage status of the sites. The sites were dying both on the well drained and the water-logged soils.

Visual symptoms of both entomological and pathological factors were found in the declining sissoo trees. Among the entomological parameters, mainly insect borers were seen. In many cases typical oozing of black to black reddish sap out of the stem was observed. This is assumed to be caused by tiny insect borers. Among pathological factors, some fungi were seen to infect the green leaves of almost all trees (e.g. Tilkane and Jatuwa-SC), leading to the decline of sissoo.

Suggested future research

The question arises what could the other reasons be behind the sissoo decline? From the Indian sissoo forest studies, the sissoo decline has been attributed mainly to pathogens, unusual climatic conditions (such as erratic rainfall, frequent extremely foggy days in winter, extreme winters and summers, water logging, fertiliser application, imbalance in soil physical characters etc). Sah and Sharma (2000) reported a slight increase in temperature in the recent years in the regions studied during the past 28 years and this is assumed to be the effect of the global warming, especially in the case of Hetauda region. The sissoo decline appeared also in the recent years. This means that there might be certain effects of the climatic changes on the sissoo forest growth. Therefore, our study concludes that, for the long-term management of the sissoo decline, periodic assessments of climatic and hydrological data from the healthy and mortality stands should be compiled and correlated with the decline in the future.

Furthermore, in the recent years (3–5 years), there was a frequent and prolonged occurrence of foggy weather during the winters in the terai. Such unusual occurrence of fog in winters may increase the amount of air pollutants in the forest and may adversely affect the forest. Therefore, we recommend to focus the future researche on the long-term monitoring and assessment of the air pollution around different regions of terai and correlate it with the sissoo forest ecosystems. A long-term forest nutrient cycling study may serve as a tool for the identification of the impacts of climatic changes, hydrology, and other abiotic factors on the forests (Schulze et al. 1989, Smith 1990). Whichever abiotic stress lies on the forests, all of them lead first of all to the imbalance or dis-coupling of the nutrient cycling, which may in extreme cases lead to the dieback of a forest. Furthermore, from the mode of such dis-coupling of the nutrient cycling, we can get some indication concerning the causal factors involved in such decline. Hence, the sissoo forest nutrient cycling should be studied as a tool in order to identify the potential causal factors involved in the decline.

Future national/international network on sissoo decline management

Now, the sissoo decline is a problem of not only Nepal and India but of the whole Indian-subcontinent such as Bhutan, Bangla Desh, Sri Lanka, Myanmar, Pakistan, etc. The decline of sissoo has also been reported from the above mentioned countries. Therefore, a strong linkage through net-working is required on the international level to monitor and combat this problem.

On the national basis, a multi-disciplinary research team should be organised to study the sissoo forests in order to identify the causes of mortality and to recommend remedial measures. As the sissoo decline research will comprise many more technical research branches, the government/donor agencies should make some exceptions to their policies of funding.

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ABSTRAKT

Možná úloha půdy během chřadnutí lesa *Dalbergia sissoo* Roxb. v oblasti nepálské terai

Studie se zabývá chřadnutím lesa tvořeného dřevinou *Dalbergia sissoo* Roxb. v rovinaté oblasti Nepálu (místně nazývané terai). Pokusili jsme se najít možného původce tohoto chřadnutí. V tomto ohledu jsme učinili některé kroky a provedli komparativní studii ve 30 rozdílných lesních porostech *D. sissoo*, které byly buď přirozené, nebo uměle vysázené. Symptomy chřadnutí této dřeviny byly proměnlivé, ale ve většině případů převládalo vrcholové odumírání koruny. Vrcholové odumírání začíná na vrcholu stromu a pokračuje postupně směrem dolů po kmeni. Dochází ke žloutnutí listů. Dodnes se předpokládalo, že jsou postiženy pouze vysázené porosty, sledovali jsme proto dřevinu *D. sissoo* rovněž na přírodních lesních stanovištích. Provedli jsme rozbor jednotlivých složek fyzikálních vlastností půdy a nezjistili jsme žádnou korelaci mezi fyzikálními půdními faktory a chřadnutím *D. sissoo*. Dospěli jsme k závěru, že půda není jediným faktorem podílejícím se na chřadnutí této dřeviny. Jsou diskutovány různé aspekty chřadnutí *D. sissoo* a jeho možné příčiny. V závěru jsou popsána budoucí strategická opatření v rámci péče o tuto dřevinu.

Klíčová slova: les tvořený dřevinou *Dalbergia sissoo* Roxb.; půdy; patogenní faktory

Corresponding author:

Dr. S.P. Sah, University of Helsinki, PL 27 Latokartanonkaari 7, FIN-00014 Helsingin Yliopisto, Finland
tel.: + 358 919 158 126, fax: + 358 919 158 100, e-mail: sambhu.sah@helsinki.fi