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# Joint Forest Management and Adaptation of Sal (*Shorea robusta*) and Its Flexibility in Wide Range of Ecological factors in Forest Gardens

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ABSTRACT

Sal (*Shorea robusta* L.) is moderate to slow growing, and can attain heights of 30 to 35 m and a trunk diameter of up to 2-2.5 m. which is a valuable forest timber which has immense innumerable uses in national as well as international level. Though, there are various ecological hindrances but, still, it has occupied its first position as forest plantation plant species world-wide. The forest people had also faced certain edaphic problems while planted thousands of plants in different forest gardens under Burdwan Forest Division in late-monsoon in the year 2017. a research team visited the forest garden several times as and when required and meet up the solution of the problems as desired with a very short time. The ultimate results fulfill the mission of the forest department through sal tree plantation in the forest garden regenerating plant population in an easy way to generate rural employment opportunity of the forest protection committee (FPC) members and the adjoining villagers in different ways. After felling the regenerated plant population serves the down-trodden people for their earning source by collecting small twigs (after pruning and thinning the forest plants in the garden) and to sale those bunch of twigs to the nearby market for their daily livelihood. Indeed, forest is open treasury to villagers. But, they abide by all the rules and regulations as stipulated by joint forest management (JFM) committee. In the FDA plantation programme, the FPC members obtain 25% incentives out total sale proceed from the forest department. The main aims and objects of this observation were to highlight the hard work of the forest employee and adjoining villagers to balance eco-system and to supply the oxygen free of cost for all. All these interesting findings have been illustrated in this context.

Keywords: Ecological hindrances, forest plantation, edaphic problems, regenerating plant populations, livelihood, oxygen free of cost, interesting findings.

## 1. INTRODUCTION

### LOCAL NAMES

Bengali (sal,shal,sakhu); English (sal); French (damar de l'Inde); German (salharzbaum, salbaum); Hindi (borsal, hal, sagua, sakhu, sakhwa, sal, shal); Nepali (agrakh, sakhua, sal, sakwa); Sanskrit (shal); Tamil (kungiliyam (resin)); Trade name (sal).

### BIOPHYSICAL LIMITS

Altitude: 100-1500 m, Mean annual temperature: (min. 1-7) 22-27 (max. 34-47) deg. C, Mean annual rainfall: 1000-3000 (max. 6600) mm.

Soil type: *S. robusta* flourishes best in deep, well-drained, moist, slightly acid sandy to clayey soils. It does not tolerate waterlogging. The most favourable soil is a moist sandy loam with good subsoil drainage. Availability of soil moisture is an important factor determining the occurrence of S. robusta. *Shorea robusta*, commonly known as sal, belongs to the *Dipterocarpaceae* family. Sal is an important non timber forest product (NTFP) and it is available in many south Asian countries like India, Pakistan, Nepal, Bhutan, Bangladesh, and Myanmar. The planning commission of India has recommended sal seed as potential NTFPs for enterprise development in India. The estimated availability of sal seed in India per year is 1.5 million tons. About 20–30 million forest dwellers depend on collection of sal seeds, leaves, and resins (Patnaik, 2015 Patnaik, S. (2015). *Non timber forest product, enterprise and forest governance*. Bhubaneswar: Center for Peoples Forestry. Sal is a large deciduous tree and it grows up to 50 m height (Figure 1). Sal tree requires well-drained, moist, and sandy loam soil. It is mostly propagated through cutting. Sal sheds leaves under dry condition from February to March and new leaves appear in the month of April and May. Fruiting and ripening occurs in summer between June and July. Sal seeds are around 10–15 mm in length and 10 mm in diameter and have five wings of unequal size and shape. The sal seed contains about 34.6%, (w/w) oil, 8.46% (w.b) moisture, and 6% ash (Singh, Soni, Kumar, & Singh, 2014 Singh, V., Soni, A., Kumar, S., & Singh, R. (2014). Pyrolysis of sal seed to liquid product. *Bioresource Technology*.

**Natural zone of sal forests (shaded dots for sal forests, after Stainton, 1972; FAO, 1985).**

Sal forests are distributed on the plains and lower foothills of the Himalayas including the valleys (Gautam, 1990). It penetrates through mid-mountain range (Mahabharat region) to the far north along river slopes and valleys. Sal forests cover ∼110 000 ha in Bangladesh (Alam, 1996), 10 million ha in India (Tewari, 1995) and 1 million ha in Nepal (HMG, 1989). This forest type extends from a few metres to 1500 m above mean sea level.

In the past, sal forests were managed solely in the interests of the ruling elite; accordingly, management norms were developed to maximize revenue (Gadgil, 1990; Gautam, 1991b; Gadgil and Guha, 1993). As timber emerged as an important commodity, the government attempted to manage sal forests for commercial timber production in order to increase revenue. Eventually, the governments saw sal forests more as a timber source rather than for other forest products. But the sal forests, to the contrary, extend to the most heavily populated zones and local people access sal forests for different uses, irrespective of whether they are designated as protective (Kumar *et al.*, 1994; Lehmkuhl, 1994; Bhat and Rawat, 1995; Aryal *et al.*, 1999) or productive forests (Nair, 1945; FRIB, 1947; Mathauda, 1958; Verma and Sharma, 1978; Rana *et al.*, 1988; Maithani *et al.*, 1989; Patnaik and Patnaik, 1991; Rajan, 1995; Tewari, 1995; Gupta *et al.*, 1996; Ganeshaiah *et al.*, 1998; Melkania and Ramnarayan, 1998; Gautam and Devkota, 1999; Pokharel *et al.*, 1999; Pokharel, 2000). It is evident that sal forests have the potential to yield other forest products, too. A sal tree in addition to timber and fuelwood, produces fodder (Panday, 1982; Gautam, 1990; Pandey and Yadama, 1990; Mathema, 1991; Upadhyay, 1992; Thacker and Gautam, 1994; Fox, 1995; Shakya and Bhattarai, 1995; Edwards, 1996; Gautam and Devkota, 1999); leaves for plates (Rajan, 1995; Gautam and Devkota, 1999); seed for oil (Verma and Sharma, 1978; Sharma, 1981); feed (Rai and Shukla, 1977; Sinha and Nath, 1982), resin or latex from heartwood (FRIB, 1947) and tannin and gum from bark (Narayanamurti and Das, 1951; Karnik and Sharma, 1968). Besides, associates of sal are known to produce edible fruits, fodder and compost, fibres, leaves for umbrellas, medicinal plants, thatch, grass, brooms and many other products depending on the species composition (Stainton, 1972; Jolly, 1976; Panday, 1982; Amatya, 1990; Gautam, 1990; Gilmour and Fisher, 1991; Mathema, 1991; Chettri and Pandey, 1992; Upadhyay, 1992; Schmidt *et al.*, 1993; Bhatnagar and Hardaha, 1994; Chandra, 1994; Jackson, 1994; Tamrakar, 1994; Thacker and Gautam, 1994; APROSC, 1995; Fox, 1995; Shakya and Bhattarai, 1995; Tewari, 1995; Edwards, 1996; Sah, 1996; Dwivedi, 1997; Melkania and Ramnarayan, 1998; Poudyal, 2000; Webb and Sah, 2003). Moreover, there are interesting facts of traditional practices of lopping, browsing and litter collection in sal forests of Nepal and elsewhere (Dinerstein, 1979; Agrawal *et al.*, 1986; Prasad and Pandey, 1987a; Chopra and Chatterjee, 1990; Pandey and Yadama, 1990; Mukhopadhyay, 1991; Upadhyay, 1992; Saxena *et al.*, 1993; Sundriyal *et al.*, 1994; Bahuguna and Hilaluddin, 1995; Bhat and Rawat, 1995; Nepal and Weber, 1995; Banerjee and Mishra, 1996; Rao and Singh, 1996; Melkania and Ramnarayan, 1998).

The evidence of such diverse products from sal forest indicates that many associate species of sal forests are capable of producing products given the appropriate management. Ecosystem-based management, i.e. 'managing ecosystems in ways compatible with both ecological processes and people's needs' (Oliver and Larson, 1996:397), could be the best option for sal forests producing 'product mixes', as required for community forestry development. Any deviation from ecosystem-based management would be neglecting the forests for the majority of the users, and eventually threatening the ecological processes of sal forests. Thus, ecosystem-based management is the present concern for sustainable management of sal forests used and managed by their local communities.

Efforts are needed to design silvicultural regimes for sal forest to produce a range of products including timber. Designing silvicultural regimes to produce multiple products over the large range of species and sites requires an understanding of the ecology and productivity of sal forests, and the influences of anthropogenic factors on its ecology and productivity. We aim to bring together the published information on ecology, productivity and anthropogenic factors relating to sal forest management. Furthermore, we are aware of the efforts to integrate various non-timber products, which are used by local communities from sal forests, into sal forest management, and have attempted to review and discuss these efforts.

## 2. MATERIALS AND METHODS

### Materials

i) Sal seeds, ii) modern nursery in forest garden, iii) necessary field area for plantation, iv) attention of the member of FPC and JFM.

### Methods

Sal seeds collected from different forest gardens in winter-summer months as routine task of the forest department. Modern nursery having all adequate facilities was availed for growing the seedling providing uniform measures in all cases. Thousands of seedlings were grown, some are early and remaining are late grown seedlings. Proper observation were provided and the data were recoded properly. It was observed that the plants were developing gradually after plantation both the early monsoon and late monsoon lots. Some plants were become affected severely after devastated condition. Some were also withering away rapidly. Research team visited the garden and started their work. First the team was collected the soil sample of the flood affected gardens and kept all the photographic documents which have been cited below. Portable soil testing kits (????) were used for the analyses of soil samples. The soil testing results of all gardens were tabulated in a single table to see all the components at a glance so that it can assessed easily to visualized the effect of deficiency or surplus the soil components over the plant population.

Photography Table-1: From nursery bed in forest garden, Burdwan Forest Division

## 3. RESULTS AND DISCUSSION

After planting the saplings in the forest garden under Burdwan Forest Division it has been found that the plants planted in late-monsoon become affected much than that of early-monsoon plantation

### Results

Soil samples were collected from the forest gardens of Burdwan Forest Division before and after devastation condition of the forest gardens. Then the soil samples were analysed in laboratory to measure its macronutrients and physical properties which have been cited in the tables separately:

**Table 1: Soil Analyses of different Forest Gardens under Burdwan Forest Division**

| Location | pH | Carbon | $N_2$ (nitrate) | $N_2$ (ammoniacal) | Phosphate | Potash |
|---|---|---|---|---|---|---|
| **Chatimdanga, Mouza–Orgram, 2015** | 6.0 (slightly acidic) | Below 0.5% (Low) | 18lbs/acre as N or 8.16 kg/ acre (Medium) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100 lbs/acre as (K) or 45.36 kg/acre (All 3 lines are visible low) |
| **Chatimdanga, Mouza–Orgram, 2018** | 6.0 (slightly acidic) | Below 0.5% (Low) | 18lbs/acre as N or 8.16 kg/ acre (Medium) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100 lbs/acre as (K) or 45.36 kg/acre (All 3 lines are visible low) |
| **Jadabgunj, Mouza–Jadabgunj, 2015** | 6.0 (slightly acidic) | Below 0.5% (Low) | 18lbs/acre as N or 8.16 kg/ acre (Medium) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100 lbs/acre as (K) or 45.36 kg/acre (All 3 lines are visible low) |
| **Jadabgunj, Mouza–Jadabgunj, 2018** | 6.0 (slightly acidic) | Below 0.5% (Low) | 18lbs/acre as N or 8.16 kg/ acre (Medium) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100 lbs/acre as (K) or 45.36 kg/acre (All 3 lines are visible low) |
| **Behind Aduria Beat office Mouza-Punrijhurgh, 2015** | 6.0 (slightly acidic) | Below 0.5% (Low) | 9lbs/acre as N or 8.16 kg/ acre (Medium) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100-250 lbs/acre as (K) or 45.36 kg/acre (All 3 lines are visible low) |
| **Behind Aduria Beat office Mouza-Punrijhurgh, 2018** | 6.0 (slightly acidic) | Below 0.5% (Low) | 9lbs/acre as N or 8.16 kg/ acre (Medium) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100-250 lbs/acre as (K) or 45.36 kg/acre (All 3 lines are visible low) |
| **Near DVC canal, Mouza–Punrijhurgh, 2015** | 6.0 (slightly acidic) | Below 0.5% (Low) | 9lbs/acre as N or 8.16 kg/ acre (Medium) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100-350 lbs/acre as (K) or 45.36 kg/acre (All 3 lines are visible low) |
| **Near DVC canal, Mouza–Punrijhurgh, 2018** | 6.0 (slightly acidic) | Below 0.5% (Low) | 9lbs/acre as N or 8.16 kg/ acre (Medium) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100-350 lbs/acre as (K) or 45.36 kg/acre (All 3 lines are visible low) |
| **Biler dhar, Mouza- Ausgram, 2015** | 6.0 (slightly acidic) | Below 0.5% (Low) | 4 lbs/acre as N or 1.81 kg/ acre as N (very low) | 13 Lbs per acre as N or 5.89 kg/acre as N (Low) | 0 Lbs per acre as $P_2O_5$ or 0 kg/acre (Blank) | Below 100 lbs/acre as (K) or 45.36 kg/acre (all three lines are visible low) |
| **Biler dhar,** | 6.0 | Below 0.5% | 45 lbs/acre as | 13 Lbs per acre as | Above 65 lbs | Below 100 lbs/acre as |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Mouza- Ausgram, 2018** | (slightly acidic) | (Low) | N or 20.41 kg/ acre as N (High ) | N or 5.89 kg/acre as N (Low) | per acre as $P_2O_5$ or 29.48 kg/acre (High) | (K) or 45.36 kg/acre (all three lines are visible low) |

***Table 2*: Growth of 14-year-old sal forest (from Jackson, 2014)**

| Species | Stems ha$^{-1}$ | Mean height (m) | Mean d.b.h. (cm) | Volume over bark (m$^3$ha$^{-1}$) | MAI over bark (0-14 years) (m$^3$) ha$^{-1}$ |
|---|---|---|---|---|---|
| **Sal** | 928 | 8.5 | 9.1 | 28.8 | 2.06 |
| **Other species** | 711 | 8.8 | 9.1 | 21.3 | 1.52 |
| **Total** | 1639 | 8.6 | 9.1 | 50.1 | 3.58 |

Rautiainen (1999) collected growth characteristics from 28 permanent sample plots located in healthy almost-pure sal forests ranging in age from 5 to 120 years (Table 5); the characteristics varied with locations within a forest (Rautiainen *et al.*, 2000). Rana *et al.* (1988) reported on the net biomass production for sal old-growth forests and sal seedling-coppice forests (Table 6). Carbon fixation in the above-ground parts of these forests was found to be 9.3 (for old-growth) and 10.1 (for new-growth) t ha$^{-1}$ year$^{-1}$, indicating greater carbon accumulation efficiency in young forest than in old forest (Rana *et al.*, 1989).

***Table 3:* Growth characteristics of almost-pure sal forests (based on Rautiainen, 1999)**

| Age (years) | Density (stem ha$^{-1}$) | Mena height (m) | Mean d.b.h. (cm) | Volume over bark (m$^3$ ha$^{-1}$) | MAI over bark (m$^3$ ha$^{-1}$) |
|---|---|---|---|---|---|
| 5 | 7633 | 5.5 | 6.2 | 68.4 | 13.68 |
| 6 | 4583 | 8.2 | 9.0 | 120.6 | 20.10 |
| 9 | 4583 | 9.1 | 9.5 | 148.7 | 16.52 |
| 13 | 2800 | 10.7 | 13.9 | 160.1 | 12.32 |
| 15 | 3416 | 12.8 | 12.1 | 203.9 | 13.59 |
| 21 | 1600 | 18.5 | 18.6 | 302.5 | 14.40 |
| 22 | 2400 | 15.2 | 15.2 | 224.7 | 10.21 |
| 40 | 528 | 24.7 | 33.5 | 413.2 | 10.33 |
| 45 | 224 | 25.9 | 36.6 | 250.6 | 5.57 |
| 80 | 257 | 20.6 | 41.6 | 170.7 | 2.13 |

## Discussion

### Ecology and productivity of sal plantation

### Standard structure

Sal is gregarious and dominant in its stand (Champion and Osmaston, 1962; Troup, 1986). It is considered to be deciduous as it changes leaves every year, and evergreen as the tree is hardly leafless. A sal tree was recorded with 45 m height, 25 m clear bole and a girth of 8 m in Nepal (Troup, 1986). Sal forest's top canopy reaches a height of 30–35 m and trees have a girth of 4 m in favourable localities, and the forest consists of many other layers of trees and shrubs. Stainton (1972) recorded species in various strata of Bhabar/Tarai and Hill sal forest (Table 1), and Rana *et al.* (1988) noted species in two types (by age) of sal forests (Table 2). The other species reveal the various types of sal forests, i.e. dry, moist or wet, and are found in varying densities depending on the edaphic and biotic conditions, and constitute a stratified height structure.

*1) Edaphic factors*

Sal grows on a wide range of soil types, except in the very sandy, gravely soils immediately adjoining rivers and in waterlogged areas (Jackson, 1994). It can grow on alluvial to lateritic soils (Tewari, 1995), and prefers slightly acidic to neutral sandy loam (pH = 5.1–6.8) with organic carbon content between 0.11 and 1.8 per cent (Rana *et al.*, 1988; Gangopadhyay *et al.*, 1990). Sal forests extend into the tropical and sub-tropical regions, and to the zones where precipitation ranges from 1000 to 2000 mm and above, and the dry period does not exceed 4 months (Tewari, 1995). Sal tolerates some frost, but annual heavy frosts occurring in frost hollows are detrimental to seedlings (Prasad and Pandey, 1987b). The maximum temperature recorded in sal forest is 49°C (Singh and Chaturvedi, 1983).

2) *Phenology*

Depending on edaphic factors and microclimate, a sal forest's phenology ranges from deciduous to evergreen and extends from tropical to sub-tropical. Leaf fall usually starts in late winter (February) and is completed by the end of April (Misra, 1969). As the sal forest consists of many other species in different layers, the phenology of the sal stand interacts with the phenology of these species (Table 3). Maximum leaf fall is from mid-February to mid-May (Pokhriyal *et al.*, 1987; Singh *et al.*, 1993a). Sal trees produce seeds every year; a good seed year is normally every third year. Seed production in sal varies (up to 500 kg $ha^{-1}$ was recorded during the early 1980s) from year to year and from tree to tree (Tewari, 1995). Seeding is normally from mid-May to mid-June.

*3) Regeneration*

Sal forest is relatively rich in ground flora diversity. Besides tree and shrub, ground flora of sal forest included fern, herb, grass and liana. The number of species in ground flora ranged from 108 to 132 in 1.2-ha plots depending on the successional stage of the forest in central Nepal (Webb and Sah, 2003), and 94 and 120 species were recorded in 0.12-ha plots in two forests in western Nepal (Gautam, 2001). Other species constituted up to 29 per cent in regeneration inventories conducted between 1 and 3 years after felling (White, 1988; Rautiainen and Suoheimo, 1997). However, regeneration studies in sal forests are mostly focused on sal species.

Sal regenerates from seed origin or by coppicing; sprouting from root suckers is also very common. Trees of both coppice and seed origin produce fertile seeds, and there is no difference in the vigour of the seedlings from coppice or seed origin (Troup, 1986). Yadav *et al.* (1986) noted middle-girth class (81- to 90-cm girth at breast height) as the best size for good-quality seed, but the size of the tree has no apparent effect on the viability of the seed (Troup, 1986).

Sal seeds have wings, and are dispersed by wind ~100 m from the mother tree (Jackson, 1994). The germination rate is very high (over 90 per cent), provided the seed gets rain within a week. A large number of seeds germinate annually. The seed loses its viability within a week, and so if the monsoon, which usually starts in late June, is delayed, the seed may fail to germinate.

Sal is a light-demanding species, and complete overhead light is needed in most cases from the earliest stages of its development (Champion and Seth, 1968; Kayastha, 1985). Opening of the canopy in a forest stand promotes regeneration, and the growth of understorey seedlings and saplings (Troup, 1986; Gautam, 1990). Some side shade, however, may be helpful under dry conditions, and young plants may require protection from frost and drought (Jackson, 1994; Tewari, 1995).

Sal tends to regenerate as a mass of seedlings where conditions (light, soil, moisture with good drainage) are favourable, and forms more-or-less even-aged crops, which are relatively pure, or it forms the bulk of the stock in mixed stands (Troup, 1986; Rautiainen and Suoheimo, 1997). Suoheimo (1999) observed 50 000–100 000 seedlings $ha^{-1}$ after regeneration felling of sal forests under uniform shelterwood system. Besides, root development in the open is generally better than under shade. Root lengths were 35.8 and 53.1 cm in two plots in the open, as against 11.9 and 18.5 cm in two plots in the shade, indicating that the vigorous growth of seedlings could be obtained by the complete removal of the overhead canopy (Troup, 1986). Similar differences of growth performances were recorded in Nepal Tarai (Suoheimo, 1999).

Only 4 per cent of the seedlings in a profusely regenerated sal-dominated mixed forest were recorded from seed origin and the rest were coppice seedlings (Suoheimo, 1999), indicating the strength of coppice origin in sal forest regeneration. Moreover, sal has a remarkable character of perennating, such as ability to coppice, and can send out young shoots following felling or die back. This process repeats year after year, and allows the cut-over sal forest to regenerate. Protection against grazing of degraded (or cleared for agriculture) land that was previously a sal forest resulted in numerous young sal shoots of uniform height, arising from roots that had survived in the ground (Jackson, 1994). The die-back rate varied from 4 to 10 per cent depending on the number of shelter trees, but no die back was recorded among the tallest 2000 seedling $ha^{-1}$ (Rautiainen and Suoheimo, 1997).

Regeneration, however, has been a serious problem in sal forest management in some parts of India, and efforts initiated since the beginning of last century have not yet been successful. Hole (1921)commenced a series of experiments in 1909 to investigate this problem and concluded that two main factors – high soil water content and poor aeration of soil in combination – were responsible for the failure of regeneration establishment. Soil water content is related to drought/precipitation and soil type, whereas bad soil aeration is caused by heavy rainfall, the presence of organic matter such as dead sal leaves and heavy grazing (Troup, 1986). The injurious actions of leaf litter were correlated with an accumulation of carbon dioxide in the soil solution and low oxygen content, and also the presence of toxic substances produced mainly by decomposition of organic matter (Troup, 1986). However, such actions and substances are injurious only under conditions of bad aeration coupled with high water content (ibid.). Sharma *et al.* (1985) suggested that poor or deficient soil aeration during monsoons and soil compaction especially during dry periods, and unfavourable topographic location, seem to be responsible edaphic factors in sal regeneration failure. Nevertheless, the information on the edaphic factors in relation to sal regeneration establishment is still scanty (Tewari, 1995).

Troup (1986) explored the mechanical effects of litter on sal seedling establishment and found that seed germinated on a layer of dead leaves under shade developed satisfactorily above ground during the first rains. In such instances, the tap roots, instead of descending into the mineral soil, spread laterally between the layers of wet leaves deriving sustenance from the moist earthy matter there, and sending out long fine lateral rootlets. All these seedlings died off when the leaf layer dried after the end of the rainy season. Such effects are reported for other species, too (Molofsky and Augspurger, 1992). On the other hand, seedlings germinated on bare ground adjacent to the plots, both under shade and in the open, produced long tap roots and achieved a firm hold in the mineral soil.

Qureshi *et al.* (1968) studied the effect of weeding and soil cultivation under three light regimes (open, partial shade and sal plantation) on the growth and establishment of sal seedlings, and found weeding and cultivation beneficial only in the open and in partial shade. Lack of light was apparently responsible for poor growth and survival in both treated and untreated areas under plantation. Khan *et al.* (1986)found higher survival and better growth of seedlings in the forest periphery than under dense canopy, signifying the role of light in forest regeneration and early growth. Light is thus very important in the development of sal stands. Light plays mainly two roles, increasing photosynthesis and ground temperature, which accelerates litter decomposition.

*4) Growth characteristics*

Growth of sal is relatively faster in the early stages; growth of 14-year-old natural regrowth mixed sal forest is given in Table 4. Rautiainen (1995) recorded current annual increment of stem volume from 17 to 18 $m^3$ $ha^{-1}$ in 6- and 9-year-old uniform-seedling coppice sal stands. Protection of degraded sal forest produced a biomass of 53.56 t $ha^{-1}$ in 4 years (Tamrakar, 1994).

*5) Growth allocations*

Boles, branches and roots, respectively, constituted 60, 24.9 and 14.7 per cent of total non-photosynthetic biomass (233.4 t $ha^{-1}$) in a forest dominated (70 per cent of total density and basal area, 95 per cent of non-photosynthetic biomass) by *S. robusta*, *Anogeissus latifolia*, *Buchnania lanzon* and *Terminalia tomentosa* (Bandhu, 1970). The weights of all tree components increased with increasing tree diameter, and of the total dry weight of the trees, bole accounted for most of the weight in all tree categories (60, 61 and 66 per cent in suppressed, average and dominant trees, respectively) in sal forest (Kaul *et al.*, 1979). In another study, Singh and Ramakrishnan (1981) partitioned the biomass of sal trees of different aged stands into bole, branch and leaf. Wood biomasses were 66, 71, 85, 91, 93 and 93 per cent (bole biomasses 53, 58, 79, 83, 88 and 88 per cent and branch biomasses 13, 13, 6, 8, 5 and 5 per cent) of the total biomass at the ages of 9, 11, 13, 15, 17 and 19 years, respectively; for the corresponding ages, the leaf biomasses constituted 34, 29, 15, 9, 7 and 7 per cent, respectively. Bole biomass and d.b.h. follow the same trend. Of the total above-ground biomass of the tree layers in sal forest, 77 and 70 per cent were found in the bole in old-growth and seedling-coppice forests, respectively (Rana *et al.*, 1988).

Singh and Chaturvedi (1983) and Singh *et al.* (1993b) found a linear relationship between circumference at breast height and current or mean annual net productivity for the young natural sal forest. Although correlations between girth and height product and biomass were also significant, girth at breast height is used more frequently in establishing the allometric relationship with biomass for sal (Singh *et al.*, 1993b).

Rana *et al.* (1988) found significant allometric relationships between biomass of the tree components (bole, branch, twig, foliage) and circumference at breast height. Similarly, positive correlation coefficients were recorded between height, girth at breast height and wood biomass and were highly significant (Suri and Dalal, 1963; Suri, 1968; Gangopadhyay *et al.*, 1990). Rao and Chaturvedi (1971) found a linear relationship between the oven-dry foliage weight and d.b.h. for sal.

*6) Productivity indices*

Raman (1976) studied the productivity of sal plantations ranging from 8 to 26 years old, and noted the same trend between basal area and net primary productivity (based on annual litter fall and current annual increment in tree biomass). The study showed 14.62 t $ha^{-1}$ $year^{-1}$ (corresponding to basal area of 29 $m^2$ $ha^{-1}$) as the highest productivity indices attained at the age of 18 years. However, the productivity based on non-green : green ratio was reported greatest between 30 and 50 years of ages (see Table 7). Sharma *et al.* (1989) used the increment in stem timber volume as a productivity index for sal forest mixed with *Mallotus philippinensis*. The above-reviewed studies indicate that the parameters such as d.b.h., basal area and stem volume are good indicators of net productivity in sal forests.

*7) Nutrient content and cycling*

Bhatnagar (1957) analysed the mineral contents (ash, CaO, MgO, N, $K_2O$ and $P_2O_5$) in sal foliage from different site quality classes, which were classified on the basis of top height at age 80 years (first quality being the tallest). First-quality trees showed the lowest concentration (per cent) of all minerals, whereas the lowest quality trees showed the highest percentage of N, P and K.

The nutrient rates calculated in the four studies show little differences in the estimates of each nutrient (Table 10). The climate of measurement years, age of the forest and methods of measurements may have contributed to these differences. One study (Kaul *et al.*, 1979) was in 21-year-old coppice forests, whereas the others were older than 35 years when they were measured. Similarly, the destructive method (trees were felled) was followed in the case of the study by Kaul *et al.* (1979) while the others followed the litter-plot method (collected throughout the year at monthly or quarterly intervals from the plots laid out in the forests).

Litter (leaves and twigs) production in sal forests ranged from 1010 to 6210 kg $ha^{-1}$ $year^{-1}$ depending on the species composition and canopy cover (Misra, 1969; Pokhriyal *et al.*, 1987). Leaf litter decomposition is faster than twig decomposition (Pande and Sharma, 1993). Maximum decomposition was in the rainy season, and turnover time to decompose the litter was 144 days (Munshi *et al.*, 1987). With the advent of rainfall usually in the last week of

June, litter starts decomposing rapidly and by the time the next litter fall starts, most of it decomposed and incorporated into the soil (Misra, 1969).

Decomposition rate increased with increasing litter moisture and air temperature and decreased with increasing altitude and lignin content (Mehra and Singh, 1985; Upadhyay and Singh, 1986). After a period of 1 year, the loss of litter for sal was observed to be 56 per cent of initial dry weight. Of the total decomposition, 40–45 per cent of litter was lost from May to August due to higher temperatures and humidity (Singh and Ramakrishnan, 1982). Total loss reached over 85 per cent by 365–669 days depending on the site and species under study (Upadhyay, 1987). During the transformation from green foliage to raw humus some of the elements (Ca, Mg, K, Na and P) were leached out while others (Si and Fe) accumulated (Gangopadhyay and Banerjee, 1987).

*8) Nitrogen translocation*

Pokhriyal *et al.* (1987) recorded a progressive increase in the nitrogen content of canopy foliage from the bottom to the top. The nutrient moves towards the upper canopy, and leaves in the lower canopy start the translocation process earlier (Pokhriyal *et al.*, 1988). Pokhriyal (1988) studied the monthly changes in N content in the canopy and litter, and estimated the retranslocated N in a natural sal forest. Foliage nitrogen content in the sal canopy was greatest (90 kg $ha^{-1}$) in January/February and least (36 kg $ha^{-1}$) in April (Pokhriyal *et al.*, 1987, 1988; Pokhriyal, 1988). Monthly N content (in percentages) in canopy, litter and storage parts (retranslocated N that sustains the growth of new foliage) of sal foliage is shown in Figure 2. Leaf litter contributed the most nutrient return, release and accumulation. Sal trees translocate nutrients from the leaves prior to leaf fall (Sharma and Pande, 1989). Translocation of N to other parts is initiated once the live canopy content peaks in January/February before leaf shedding starts. From January to April, canopy nitrogen is either translocated (0 per cent in January to maximum 42.5 per cent in April) to other parts or returned to the ground through litter (Pokhriyal *et al.*, 1987).

*9) Successional stages of sal forests*

Broadly, the sal forest types are identified as dry sal, moist sal, coastal sal and wet sal (Champion and Osmaston, 1962). However, they can be separated into two extreme types, the dry and the wet; between these, various gradations occur (Troup, 1986). These two types occur in a continuum from east to west; extreme wet sal forests are prevalent in the east and at the other extreme, dry, in the west. Based on the associated species, the distinction between these two types of forest appears to be a fine one (Stainton, 1972). However, Stainton (1972) classified the sal forests of Nepal into Bhabar and Tarai sal forest and Hill sal forest, and the situation outside Nepal supports this classification. Bhabar and Tarai sal grow to a considerable size, whereas in Hill sal much smaller trees are found. In a north–south transect, Hill sal is drier than the Bhabar and Tarai sal.

Sal forest's present status is the result of actions and interactions of environmental and biotic factors, and is explained in terms of plant succession theories (Champion and Osmaston, 1962; Troup, 1986). The developmental process involves progression and retrogression (Figures 3–5). Grazing and fire are prevalent in sal forests, and the extent of their presence affects the successional pathways into progression and retrogression (Lehmkuhl, 1994).

*10) Fire*

Fire has long been considered one of the main factors affecting (beneficially or injuriously) sal stand development (see Figures 3–5) depending on the forest type and local situation (Jacob, 1941; Champion and Osmaston, 1962; Maithani *et al.*, 1986, 1989; Troup, 1986; Lehmkuhl, 1994). Fire was once considered the only weapon available to foresters for controlling weeds (Champion and Osmaston, 1962). Controlled burning was also prescribed to eliminate the injurious effect of dead leaves. Burning of leaf litter just before seeding was used to ensure good regeneration (Troup, 1986). Fire was extensively and intentionally used to promote regeneration and maintain the sal forest as the climax type in wet sal forest regions in India (Jacob, 1941).

Fire did not change the tree layer parameters (species composition and density) but changed the shrub structure (Rodgers *et al.*, 1986). Ground vegetation, including regenerating trees, was modified, and some species disappeared while new ones appeared (Raynor, 1940; Jacob, 1941; Nair, 1945; Maithani *et al.*, 1986; Rodgers *et al.*, 1986). In all these instances, fire increased the number of herbs and shrubs, especially palatable plants. Fire also attracted additional grazing by reducing the height of many palatable shrubs (Maithani *et al.*, 1986; Rodgers *et al.*, 1986), and together these factors negatively affected sal regeneration. Eventually, fire and wildlife grazing controlled successional pathways (Lehmkuhl, 1994). Older trees were resistant to fire, but the wounds from fire in sal trees between 15 and 35 years of age resulted in infection and the trees became prone to heart rot due to fungi (Bakshi, 1957).

Most studies indicated that sal trees can resist fire once they have passed the sapling stage. Controlled burning or grazing is necessary to prevent the wet sal forest from becoming mixed broadleaved forest (Figure 5). Moreover, controlled burning creates opportunities for regeneration of many non-timber forest product (NTFP) species. In several instances, intentional forest fires have been recorded in sal forests normally ignited by the NTFP collectors, harvestors or gatherers.

## 4. CONCLUSION

Managing sal forest for multiple products is a relatively recent development with sporadic instances of local management for timber and non-timber forest products. Multiple-product forest management appears not only desirable but also essential for sustaining sal forests in the region, for both ecological and socio-economic reasons. Implementation of community-based forestry programmes requires a commitment from local communities as well as policy makers towards managing sal forest for multiple products. Despite the requirements for multiple-product forestry, scientific information is still scanty, and further forest research is needed. Silviculturists are expected to respond to the continually changing demands on existing stands (Oliver and Larson, 1996). Sal forests, seen historically as timber sources, are to be managed now for multiple products, and this necessitates evolving silvicultural regimes. Foresters must now increase productivity (in quality and quantity) through silviculture that is sustainable and protect sal forest biodiversity.

Leaf shedding creates opportunities to regenerate many species of ground flora. Leaf nitrogen translocation before leaf fall, for example, could reduce the adverse effect of ground litter removal or ground fire.

## REFERENCES

Agrawal, A.K., Joshi, A.P., Kandwal, S.K. and Dhasmana, R. 1986. An ecological analysis of Malin riverain forest of outer Garhwal Himalaya (western Himalaya). Indian J. Ecol. 13, 15–21.

Alam, M.K. 1996. Diversity in the woody flora of sal (*Shorea robusta*) forests of Bangladesh. Bangladesh J. For. Sci. 24, 41–51.

Amatya, S.M. 1990. *Fodder Trees and Their Lopping Cycle in Nepal.* B. M. Amatya Tahachal, Kathmandu.

APROSC. 1995. *Forest Managment Plan for Sarlahi District.* Agricultural Projects Service Center, Kathmandu.

Aryal, B., Giri, A., Shrestha, K.K., Ghimire, S.K. and Jha, P.K. 1999. Vegetation analysis of *Shorea robusta* forests in the Royal Bardia National Park, Nepal. Bangladesh J. Bot. 28, 35–46.

Bahuguna, V.K. and Hilaluddin. 1995. Plant community classification and ordination of sal forests of Bankura (north) forest division of West Bengal, India.Van Vigyan. 33, 87–103.

Bakshi, B.K. 1957. Heart-rots in relation to management of sal. Indian For. 83, 651–661.

Bandhu, D. 1970. A study of the productive structure of northern tropical dry deciduous forests near Varanasi. I. Stand structure and non-photosynhetic biomass. Trop. Ecol. 11, 90–104.

Banerjee, S.K. and Mishra, T.K. 1996. Extension of forestry research through joint forest management: an ecological impact study. Adv. For. Res. India. 14, 11–25.

Bhat, S.D. and Rawat, G.S. 1995. Habitat use by chital (*Axis axis*) in Dhaulkhand, Rajaji National Park, India. Trop. Ecol. 36, 177–189.

Bhatnagar, H.P. 1957. Mineral constituents of foliage of sal (*Shorea robusta*), of different quality classes. Indian For. 83, 647–650.

Bhatnagar, P. and Hardaha, S. 1994. Socio-economic potential of non-wood forest products: a case study of Karanjia block. Vaniki Sandesh.18, 11–22.

Champion, H. and Osmaston, F.C. (eds). 1962 *E. P. Stebbing's The Forests of India.* Volume IV. Oxford University Press, London.

Champion, H.G. and Seth, S.K. 1968. *General Silviculture for India.* Government of India, Delhi.

Chandra, S. 1994. Rural development through forest-based cottage industries. Vaniki Sandesh 18, 1–5.

Chettri, R.B. and Pandey, T.R. 1992. *Users Group Forestry in the Far-Western Regions of Nepal (Case Studies from Baitadi and Achham).* International Centre for Integrated Mountain Development, Kathmandu.

Chopra, S. and Chatterjee, D. 1990. Integrating conservation and development: a case study of the socio-economic forestry complex at Arabari, West Bengal. Int. Tree Crops J. 6,193–204.

Dinerstein, E. 1979. An ecological survey of the Royal Karnali-Bardia Wildlife Reserve, Nepal. Part I: vegetation, modifying factors, and successional relationships. Biol. Conserv. 15, 127–150.

Dwivedi, A.P. 1997. *Forests, the Non-wood Resources.* International Book Distributers, Dehradun, India.

Edwards, D.M. 1996. *Non-timber Forest Products from Nepal.* Forest Research and Survey Centre, Kathmandu, 134 pp.

FAO. 1985. *Dipterocarps in South Asia.* FAO Regional Office for Asia and Pacific, Bangkok.

Fox, J. 1995. Non-timber forest products in a Nepalese village in 1980 and 1990. In *Society and Non-timber Forest Products in Tropical Asia*. J. Fox (ed.). East-West Center Occasional Papers Environment Series No. 19, pp. 37–51.

FRIB. 1947. Experimental tapping of sal and blue pine.Forest Resource India Burma 1945–61, 88–90.

Gadgil, M. 1990. India's deforestation: patterns and processes. Soc. Nat. Resour. 3, 131–143.

Gadgil, M. and Guha, R. 1993, *The Fissured Land: An Ecological History of India.* University of California Press, Berkeley.

Ganeshaiah, K.N., Shhanker, R.U. and Bawa, K.S. 1998. Extraction of non-timber forest products in the forests of Bilgiri Rangan Hills, India. 5. Influence of dispersal mode on species response to anthropogenic pressures. Econ. Bot. 52, 316.

Gangopadhyay, S.K. and Banerjee, S.K. 1987 The influence of vegetation on the properties of the soils of Sikkim. Biol. Sci. 53, 283–288.

Gangopadhyay, S.K., Nath, S., Das, P.K. and Banerjee, S.K. 1990.Distribution of organic matter in coppice sal (*Shorea robusta*) in relation to soil chemical attributes. Indian For. 116,407–417.

Gautam, K.H. 1990. *Regeneration Status of Sal (Shorea robusta) Forests in Nepal*. Department of Forest Nepal, Kathmandu, 11 pp.

Gautam, K.H. 1991. a Forestry as a means to sustain the power of politicians. In *Ecopolitics-V, Sydney, Australia.* Centre for Liberal and General Studies, University of New South Wales, Sydney.

Gautam, K.H. 1991b. *Indigenous Forest Management Systems in the Hills of Nepal*. Department of Forestry, Australian National University, Canberra.

Gautam, K.H. 1995. *Hidden Corners of Community Forestry: Potential for Exploring Towards Sustainability*. District Forest Office Sindhupalchok, Chautara, Nepal, 24 pp.

Gautam, K.H. 2001. *Lopping Regimes in Community-Managed Sal (Shorea robusta) Forests of Nepal: Prospects for Multiple-Product Silviculture for Community Forestry*. School of Forestry, University of Canterbury, Christchurch, 267 pp.

Gautam, K.H. and Devkota, B.P. 1999. Sal (*Shorea robusta*) leaves can provide income to some community forestry user groups at Sindhupalchok district. Nepal J. For. 11,39–46.

Gilmour, D.A. and Fisher, R.J. 1991. *Villagers, Forests and Foresters: The Philosophy, Process and Practice of Community Forestry in Nepal*. Shahayogi Press, Kathmandu.

Gupta, R.K., Chauhan, A. and West, N.E. 1996. Restoration of degraded rangelands and biodiversity of the Siwalik Hills between the Ganga and Yamuna rivers, India. Rangelands in a sustainable biosphere. In *Fifth International Rangeland Congress, Salt Lake City, Utah, USA.* Society for Range Management, Denver, CO.

HMG.1989. *Master Plan for the Forestry Sector Nepal.* Ministry of Forests and Soil Conservation, His Majesty's Government, Nepal.

Hole, R.S. 1921. Regeneration of sal (*Shorea robusta*) forests. A study in economic ecology, Indian Forest Record, Silviculture (Old Series), 8(2).

Jackson, J.K. 1994. *Manual of Afforestation in Nepal.* Forest Research and Survey Centre, Kathmandu. Jacob, M.C. 1941.Sal regeneration de novo a rejoinder. Indian For. 67,337–346.

Jashimuddin, M., Rahman, M.M., Hossain, M.S. and Shakil, A.1999. Status of Birol sal forest in north western Bangladesh. J. Trop. For. Sci.11, 654–656.

Jolly, M.S. 1976. Silk from forest. Unasylva 28, 20–23.

Karnik, M.G. and Sharma, O.P. 1968. Cellulose gums from sal (*Shorea robusta*) bark and Bamboo (*Dendrocalamus strictus*). Indian Pulp Paper 22, 451–453.

Kaul, O.N., Sharma, D.C. and Srivastava, P.B.L. 1979. Distribution of organic matter and plant nutrients in a sal (*Shorea robusta*) coppice plantation. Indian For. 105, 171–179.

Kayastha, B.P. 1985. *Silvics of the Trees of Nepal.* Community Forestry Development Project, Kathmandu.

Khan, M.L., Rai, J.P.N. and Tripathi, R.S. 1986. Regeneration and survival of tree seedlings and sprouts in tropical deciduous and sub-tropical forests of Meghalaya, India. For. Ecol. Manage. 14, 293–304.

Kumar, R., Singh, A.K. and Abbas, S.G. 1994. Change in population structure of some dominant tree species of dry peninsular sal forest. Indian For. 120, 343–348.

Lehmkuhl, J.F. 1994. A classification of subtropical riverine grassland and forest in Chitawan National Park, Nepal. Vegetatio 111, 29–43.

Maithani, G.P., Bahuguna, V.K. and Lal, P. 1986. Effect of forest fires on the ground vegetation of a moist deciduous sal (*Shorea robusta*) forest. Indian For. 112, 646–678.

Maithani, G.P., Sharma, D.C. and Bahuguna, V.K. 1989. Problems of sal forests – an analysis. Indian For. 115, 513–525.

Mathauda, G.S. 1958. The unevenaged sal forests of Ramnagar Forest Division, Uttar Pradesh: their constitution, rate of growth and drain along with empirical yield and stand tables for selection type of sal crops. Indian For. 84, 255–269.

Mathema, P. 1991. Sal regeneration management. Nepal J. For. 6, 112–114.

Mehra, M.S. and Singh, J.S. 1985. Pattern of wood litter fall in five forests located along an altitudinal gradient in central Himalaya. Vegetatio 63, 3–11.

Melkania, N.P. and Ramnarayan, K. 1998. Influence of forest floor sweeping on chemical properties of lateritic soils in sal coppice forest, West Bengal, India. In *Red and Lateritic Soils, Volume 1: Managing Red and Lateritic Soils for Sustainable Agriculture*. J. Sehgal, W.E. Blum and K.S. Gajbhiye (eds). A. A. Balkema, Rotterdam, Netherlands, pp. 403–406.

Misra, R. 1969. Studies on the primary productivity of terrestrial communities at Varanasi. Trop. Ecol. 10, 1–15.

Misra, R., Singh, J.S. and Singh, K.P. 1967. Preliminary observations on the production of dry matter by sal (*Shorea robusta* Gaertn. f.). Trop. Ecol. 8, 94–104.

Molofsky, J. and Augspurger, C.K. 1992. The effect of leaf litter on early seedling establishment in a tropical forest. Ecology. 73, 68–77.

Mukhopadhyay, S. 1991. Tribal area development through forest resource management: a study on southern Banduan police station of Purulia district, West Bengal. Indian J. Region. Sci. 23, 59–67.

Munshi, J.D., Hussain, M.A. and Verma, H.K. 1987. Leaf litter dynamics of *Shorea robusta* plantation in a deciduous forest of Munger, Bihar. Environ. Ecol. 5, 374–377.

Nair, K.N.R. 1945. The problem of sal regeneration in Mayurbhanj. Indian For. 71, 127–129.

Narayanamurti, D. and Das, N.R. 1951. A preliminary note on adhesives, building boards, and moulding powders from tree's bark. Indian For. 77, 706–708.

Nepal, S.K. and Weber, K.E. 1995. Prospects for coexistence: wildlife and local people. Ambio 24, 238–245.

Oliver, C.D. and Larson, B.C. 1996. *Forest Stand Dynamics.* Wiley, Singapore.

Panday, K.K. 1982. *Fodder Trees and Tree Fodder in Nepal.* Swiss Development Cooperation, Berne.

Pande, P.K. and Sharma, S.C. 1988. Litter nutrient dynamics of some plantations at new forest, Dehra Dun (India). J. Trop. For. 4, 339–349.

Pande, P.K. and Sharma, S.C. 1993. Litter decomposition in some plantations(India).
Ann. For. 1, 90–101.

Pandey, S. and Yadama, G.N. 1990. Conditions for local level community forestry action: a theoretical explanation. Mount. Res. Dev. 10, 85–95.

Patnaik, R.K. and Patnaik, G.N. 1991. Effects of feeding sal (Shorea robusta) leaves on the performance of crossbred jersey cows under farm conditions in Orissa. Indian Vet. J. 68, 1186–1187.

Pokharel, R.K. 2000. From practice to policy – squatters as forest protectors in Nepal: an experience from Shrijana forest user group. For. Trees People Newsl. 42**,** 31–35.

Pokharel, R.K., Adhikari, S.N. and Thapa, Y.B. 1999. Sankarnagar forest user group – learning from a successful FUG in the Tarai. For. Trees People Newsl. 38**,** 25–32.

Pokhriyal, T.C. 1988. Mobilization and recycling of nitrogen contents in *Shorea robusta* follage. Indian J. Plant 31, 158–162.

Pokhriyal, T.C., Ramola, B.C. and Raturi, A.S. 1987. Soil moisture regime and nitrogen content in natural sal forest (*Shorea robusta*). Indian For. 113, 300–306.

Pokhriyal, T.C., Ramola, B.C., Bisht, M.S., Nautiyal, H.O. and Unnikrishnan, K.P.

1988. Effect of seasonal variation on nitrate contents in natural sal forest (*Shorea robusta*). Indian For. 114, 784–789.

Poudyal, A.S. 2000. *Wildlife corridor management: analysis of biodiversity and socioeconomics in the buffer zone of the Royal Chitawan National Park, Nepal.* Asian Institute of Technology, Bangkok.

Prasad, R. and Pandey, R.K. 1987. a Survey of medicinal wealth of central India.
J. Trop. For. 3, 287–297.

Prasad, R. and Pandey, R.K. 1987. b Vegetation damage by frost in natural forests of Madhya Pradesh. J. Trop. For. 3, 273–278.

Qureshi, I.M., Srivastava, P.B.L. and Bora, N.K.S. 1968. Sal (*Shorea robusta*) natural regeneration de-novo. Effect of soil working and weeding on the growth and establishment. Indian For. 94, 591–598.

Rajan, R.P. 1995. Sal leaf plate processing and marketing in West Bengal. In *Society and Non-timber Forest Products in Tropical Asia.* J. Fox (ed.). East-West Center, Honolulu, pp. 27–36.

Raman, S.S. 1976. Biological productivity of *Shorea* plantations.
Indian For. 102, 174–184.

Rana, B.S., Singh, S.P. and Singh, R.P. 1988. Biomass and productivity of central Himalayan sal (*Shorea robusta*) forest. Trop. Ecol. 29, 1–7.

Rana, B.S., Singh, S.P. and Singh, R.P. 1989. Carbon and energy dynamics of seven central Himalayan forests. Trop. Ecol. 30, 253–264.

Rao, A.R. and Singh, B.P. 1996. Non-wood forest products contribution in tribal economy. Indian For. 122, 337–342.

Rao, B.K.S. and Chaturvedi, A.N. 1971. Foliage relationships in sal (*Shorea robusta*).
Indian For. 97, 638–645.

Rautiainen, O. 1995. Trust in sal. Banko Janakari 5, 88–89.

Rautiainen, O., Pukkala, T. and Miina, J. 2000. Optimising the management of even-aged *Shorea robusta* stands in southern Nepal using individual tree growth models.

For. Ecol. Manage. 126, 417–429.

Rautiainen, O. and Suoheimo, J. 1997. Natural regeneration potential and early development of *Shorea robusta* Gaertn.f. forest after regeneration felling in the Bhabar–Terai zone in Nepal. For. Ecol. Manage. 92, 243–251.

Raynor, E.W. 1940. Sal regeneration de novo. Indian For. 66, 525–529.

Rodgers, W.A., Bennet, S.S.R. and Sawarkar, V.B. 1986. Fire and vegetation structure in sal forests, Dehra Dun, India. Trop. Ecol. 27, 49–61.

Sah, S.P. 1996. Natural regeneration status of sal (*Shorea robusta* Gaertn.) forests in Nepal. In *Modelling Regeneration Success and Early Growth of Forest Stands.* J.P. Skovsgaard, and V.K. Johannsen (eds). Danish Forest and Landscape Research Institute, Horsholm, pp. 139–143.

Saxena, K.G., Rao, K.S. and Purohit, A.N. 1993. Sustainable forestry – prospects in India. J. Sustainable For. 1, 69–95.

Schmidt, M.G., Schreier, H. and Shah, P.B. 1993.Factors affecting the nutrient status of forest sites in a mountain watershed in Nepal. J. Soil Sci. 44, 417–425.

Seth, S.K., Kaul, O.N. and Gupta, A.C. 1963. Some observations on nutrient cycle and return of nutrients in plantation at New Forest. Indian For. 89, 90–98.

Shakya, C.M. and Bhattarai, D.R. 1995. *Market Survey of Non-wood Forest Products in Baa and Rautahat Districts for Operational Forest Management Plans.* Forest Management and Utilization Development Protect, Department of Forest, Kathmandu, Nepal, 30 pp.

Sharma, S.C. and Pande, P.K. 1989. Patterns of litter nutrient concentration in some plantation ecosystems. For. Ecol. Manage. 29, 151–163.

Sharma, S.D., Banerjee, S.P., Rawat, V.R.S., Raina, A.K. and Singh, B. 1989. Present productivity of soils supporting sal (*Shorea robusta*) in Doon Valley, Uttar Pradesh. J. Indian Soc. Soil Sci. 37, 539–544.

Singh, J. and Ramakrishnan, P.S. 1981. Biomass and nutrient movement through litter in *Shorea robusta* Gaertn. plantations in Meghalayay. Proc. Indian Natl Sci. Acad. B.
47, 852–860.

Singh, J. and Ramakrishnan, P.S. 1982. Structure and function of a sub-tropical humid forest of Meghalaya II. Litter dynamics and nutrient cycling. Proc. Indian Acad. Sci. Plan. 91, 255–268.

Singh, O., Sharma, D.C. and Rawat, J.K. 1993. a Production and decomposition of leaf litter in sal, teak, Eucalyptus and poplar forests in Uttar Pradesh. Indian For. 119, 112–121.

Singh, R.P. and Chaturvedi, O.P. 1983. Primary production of a deciduous forest at Varanasi. Indian For. 109, 255–260.

Singh, R.P., Rana, B.S. and Garkot, S.C. 1993b. Biomass and production patterns of three dominant tree species along a girth series in a natural tropical forest at Chakia, Varanasi (India). Indian For. 119, 472–480.

Singh, V., Soni, A., Kumar, S., & Singh, R. (2014). Pyrolysis of sal seed to liquid product. *Bioresource Technology*, *151*, 432–435.10.1016/j.biortech.2013.10.087

Sinha, R.P. and Nath, K. 1982. Effect of urea supplementation on nutritive value of deoiled sal-meal in cattle. Indian J. Anim. Sci. 52, 1165–1169.

Stainton, J.D.A. 1972. *Forests of Nepal.* John Murray, London.

Sundriyal, R.C., Sharma, E., Rai, L.K. and Rai, S.C. 1994. Tree structure, regeneration and woody biomass removal in a sub-tropical forest of Mamlay watershed in the Sikkim Himalaya Vegetation. 113, 53–63.

Suoheimo, J. 1999. Natural reneration of sal (Shorea robusta) in the Terai region, Nepal. University of Helsinki, Helsinki, 134 pp.

Suri, S.K. 1968. Estimation of the total amount of foliage in sal (*Shorea robusta*) trees and stands (sal). Indian For. 94, 653–656.

Suri, S.K. and Dalal, S.S. 1963. Study of some vegetational factors of *Shorea robusta* (sal). Indian For. 89, 134–141.

Tamrakar, P.R. 1994. Coppice management of *Shorea robusta* forests in Nepal.
Banko Janakari. 4,176–179.

Tamrakar, P.R. and Danbury, D.J. 1997. Silviculture by rural people in the middle hills of Nepal. Banko Janakari 7, 9–16.

Tewari, D.N. 1995. *A Monograph on Sal (Shorea robusta Gaertn. f.).* International Book Distributors, Dehradun, India.

Thacker, P. and Gautam, K.H. 1994. *A Socioeconomic Study of Participatory Issues in Forest Management in the Terai. Forest Management and Utilization Development Project (FMUDP)*, Department of Forests, Nepal, 95 pp.

Troup, R.S. 1986. *The Silviculture of Indian Trees.* International Book Distributors, Dehradun, India.

Upadhyay, L.R. 1992. Use of tree fodder in Jhapa and Sunsari districts in the eastern Terai. Banko Janakari. 3, 17–18.

Upadhyay, V.P. 1987. Leaf litter decomposition and calcium release in forests of central Himalaya. J. Trop. For. 3, 242–253.

Upadhyay, V.P. and Singh, J.S. 1986. Decomposition of woody branch litter on an altitudinal transect in the Himalaya. Vegetation. 64, 49–53.

Verma, V.P.S. and Sharma, B.K. 1978. Studies on production and collection of sal (*Shorea robusta* Gaertn.) seeds. Indian For. 104, 414–420.

Webb, E.L. and Sah, R.N. 2003. Structure and diversity of natural and managed sal (Shorea robusta Gaertn.f.) forest in the Terai of Nepal. For. Ecol. Manage. 176, 337- 353.

White, K.J. 1988. *Manual 2. Tree Farming Practices in the Bhabar Terai of Central Nepal*. Ministry of Forests, Kathmandu, Nepal, 40 pp.

Yadav, V.K., Khare, P.K. and Mishra, G.P. 1986. Effect of tree girth on seed viability and germination in sal. J. Trop. For. 2,160–163.

**Table 4: Some photographs in different stages of sal (Shorea robusta) from different forest gardens**

**Photo 1: Burdwan Forest Division**


**Photo 2: Burdwan Forest Division**

**Photo 3: Bankura (S) Forest Division**

| | | |
|---|---|---|
| <br>**Photo 4: Bankura (S) Forest Division** | <br>**Photo 5: Bankura (S) Forest Division** | <br>**Photo 6: Bankura (S) Forest Division** |
| <br>**Photo 7: Burdwan Forest Division** | <br><br>**Photo 8: Burdwan Forest Division** | <br>**Photo 9: Burdwan Forest Division** |
| <br>**Photo 10: Burdwan Forest Division** | <br>**Photo 11: Burdwan Forest Division** | <br>**Photo 12: Burdwan Forest Division** |