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Wood properties in relation to foliar phenology of some planted tree species at Kirtipur, central Nepal

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Abstract: Wood water content (WWC), wood saturated water content (WSWC) and wood density (D_w) were measured in planted *Pinus roxburghii* (chir pine), *Alnus nepalensis* (alder) and *Populus* x *euramericana* (poplar)) for one year from (March 2002 to February 2003) at monthly intervals. Phenological events were recorded by frequent visits during the same period. Chir pine and alder retained mature leaves during winter and early summer. Chir pine is unusual in having very short (only 13 months) leaf life span among the pines. With decreasing leaf life span, from chir pine (13 months), alder (10 months) to poplar (7 months), (D_w) wood density decreased, and wood water content (WWC) and wood saturated water content (WSWC) increased. All three species had their highest D_w in late October. Species with high D_w had low WSWC ($R = 0.91$, $p < 0.001$). These three species were significantly different with respect to D_w. Both leaf production and leaf fall were more concentrated in poplar and chir pine than in alder. Prolonged leaf production in alder appears to be associated with its inherent behavior as an early successional species, and a reduction in leaf area due to insect herbivory. Despite their unequal leaf life span, all species began new growth (bud break and leaf flushing) during the dry, hot summer season. Water stored in the stem and that conserved by reduction in transpirational loss due to leaf fall (in chir pine and alder) was availablbe for leaf initial growth. It appears that climate data alone could not explain the water relations as well as phenology of these trees.

Resumen: El contenido de agua en la madera (WWC), el contenido de agua en la madera saturada (WSWC) y la densidad de la madera (D_w) fueron medidos en árboles plantados de *Pinus roxburghii* (pino chir), *Alnus nepalensis* (aile) y *Populus* x *euramericana* (álamo) a intervalos mensuales durante un año, de marzo de 2002 a febrero de 2003. Los eventos fenológicos fueron registrados a través de visitas frecuentes durante el mismo periodo. El pino chir y el aile retuvieron las hojas maduras durante el invierno y principios del verano. El pino chir es inusual entre los pinos por tener una longevidad foliar muy corta (de tan sólo 13 meses). Con una longevidad foliar decreciente del pino chir (13 meses), el aile (10 meses) al álamo (7 meses), la densidad de la madera (D_w) disminuyó y el contenido de agua de la madera (WWC) aumentó, al igual que el contenido de agua en la madera saturada (WSWC). Las tres especies tuvieron su D_w más alta a finales de octubre. Las especies con alto D_w tuvieron valores bajos de WSWC ($R = 0.91$, $p < 0.001$). Las tres especies difirieron significativamente respecto a D_w. Tanto la producción como la caída de hojas estuvieron más fuertemente concentradas en el álamo y el pino chir que en el aile. La producción foliar prolongada del aile parece estar asociada a su comportamiento inherente de especie sucesionalmente temprana y a una reducción en el área foliar debida a la herbivoría por insectos. No obstante sus longevidades

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foliares desiguales, todas las especies iniciaron un nuevo crecimiento (reactivación de las yemas e iniciación foliar) durante la estación veraniega seca y caliente. El agua almacenada en el tallo y la conservada por reducción en la pérdida transpiracional debida a la caída de las hojas (en el pino chir y el aile) estuvo disponible para el crecimiento foliar inicial. Aparentemente los datos climáticos solos no pudieron explicar las relaciones hídricas ni la fenología de estos árboles.

Resumo: O teor em água e o teor de saturação em água do lenho (WSWC) e a sua densidade (D_w) foram medidos em intervalos de um mês em *Pinus roxburghii* (chir pine), *Alnus nepalensis* (amieiroo) e *Populus* x *euramericana* (choupo) plantados por um ano, de Março de 2002 a Fevereiro de 2003. Os acontecimentos fenológicos foram registados em visitas frequentes durante o mesmo período. O "chir pine" e o amieiro retiveram as folhas maduras durante o inverno e o início do verão. Neste pinheiro é pouco usual a ocorrência de um curto período de vida das folhas (só 13 meses) como entre os pinheiros. O período de vida decrescente das folhas vai do "chir pine" (13 meses) ao amieiro (10 meses) seguindo-se o choupo (7 meses), enquanto a densidade da madeira (D_w) decresceu e o teor de água na mesma (WSWC) aumentou. As três espécies apresentaram a mais elevada D_w no fim de Outubro. As espécies com o valor de D_w mais elevado apresentavam o valor de WSWC ($R = 0.91$, $p < 0.001$) mais baixo. Estas três espécies eram significativamente diferentes em relação a D_w. Quer a produção de folha quer a queda da mesma apresentaram-se mais concentradas no choupo e "chir pine" do que no amieiro. O período prolongado de produção de folha no amieiro parece estar associado com o comportamento herdado como espécie dos períodos iniciais da sucessão e a redução da área foliar devido a desfolha de insectos herbívoros. Apesar da duração desigual de vida, todas as espécies iniciam o seu ciclo vegetativo (renovo e rebentação das folhas) durante a estação seca quente de verão. O armazenamento da água no tronco e a conservada por redução das perdas por transpiração pela queda das folhas (no chir pine e no amieiro) fica disponível para o crescimento inicial das folhas. Parece que os dados climáticos por si sós não podem explicar as relações hídricas nem a fenologia destas árvores.

Key words: *Alnus nepalensis*, *Pinus roxburghii*, phenology, *Populus x euramericana,* wood density, wood saturated water content.

Introduction

Phenology deals with the study of different life events of plants such as seed germination, bud break, leaf expansion, leaf color change, leaf fall, flowering and fruiting. Reproductive phenology (germination, flowering and fruiting) is important for ecosystem structure while foliar phenology controls ecosystem functions such as nutrient dynamic (Singh & Singh 1992). Foliar phenology is largely controlled by temperature in general and also by precipitation (total amount and seasonal distribution) through the change in soil moisture and tree water status (Reich & Borchert 1984) and photoperiod (Hanninen 1995). But some internal plant factors, such as water status and water storage capacity of the tree trunk, also have significant control over foliar phenology (Borchert 1994). Plant water status is controlled by absorption and transpiration; however, these two processes are not tightly coupled because of the capacitance factor provided by readily available water stored in the trunks of large trees (Kramer & Boyer 1995). The water stored in the tree trunk buffers the impact of seasonal drought and enables flushing and flowering during the dry season in trees of American dry tropical forests (Borchert 1994) and the Central Himalayan region (Shrestha *et al.* 2006). Leafless period (reflecting the extent of drought experienced by tree species in Vindhyan forests was found to be negatively correlated with stem wood density (Kushwaha & Singh 2005).

Different tree species growing in the same climate and similar soil conditions may differ in characteristics such as leaf life span, wood water content (WWC), wood saturated water content (WSWC) and wood density (D_w). WWC and WSWC are largely determined by D_w (Borchert 1994). The D_w is a highly conserved character within woody the taxa (Carlquist 1980) and closely related to many physiological and hydraulic properties of trees (Stratton *et al.* 2000). Variation in D_w is a strong predictor of variation in a suite of characteristics related to efficiency and integrity of leaf water balance and avoidance of turgor loss (Meinzer 2003). Since foliar phenology and wood properties (WWC, WSWC and D_w) both have evolutionary, structural and functional significance, understanding their relationship may help to understand the distribution pattern of tree species. This study aimed to determine these interrelationships in three important tree species (*Pinus roxburghii* Sarg. (chir pine), *Alnus nepalensis* D.Don. (alder) and *Populus x euramericana* (poplar)) used for plantations in Nepal. Chir and alder also occur in natural forests of sub-tropical and temperate regions in Nepal (Jackson 1994).

Materials and methods

Study site

The study included afforested land in the southwestern part of Kathmandu valley. The plantation was 35 year old. The study site (27°40'-41' N and 85°16'-18' E; alt. 1300-1400 m) lies within the Tribhuvan University Campus at Kirtipur. The chir pine plantation is on a relatively dry site, mixed with *Acacia* sp. The alder and poplar plantations are on moist sites; both are pure stands, with a dense understory of *Lantana camara* (an exotic shrub). The average sizes of sampled trees were: chir pine - height 13.3 m, diameter at breast height (dbh) 34 cm; alder - height 22 m, dbh 22 cm; poplar - height 27 m, dbh 51 cm. Average tree density of the stands were: 345 stem ha^{-1} for chir pine, 360 stem ha^{-1} for alder and 275 stem ha^{-1} for poplar.

The climate has three distinct seasons: hot and dry summer (February to May), hot and moist rainy season (June to September) and cold and dry winter (October to January). Total rainfall during the study period (1 year) was 1888 mm, with 75% during the rainy season. Highest mean maximum temperature was 29.3 °C in June 2002 and lowest mean minimum temperature 2.0 °C in January 2003 (Fig. 1).

Species characters

Pinus roxburghii Sarg. (Pinaceae; common name; chir pine) has three needle leaves in a fascicle. The leaf longevity is nearly 13 months (Shrestha *et al.* 2006) and maximal height 40-50 m or more (Richardson & Rundel 1998). Chir pine usually grows between 900 and 1950 m elevation but in sheltered valleys of foothills it descends to as low as 450 m and in dry upper valleys it ascends to 2700 m (Jackson 1994). It is more common on the dry, south facing slope of hills. It is an important source of timber, fuel wood, and resin.

Alnus nepalensis D. Don. (Betulaceae; common name; alder) is distributed across the Himalayas from Upper Burma to Kumaon (Jackson 1994). It occurs from 500 to 2700 m but is more common above 900 m. It is a pioneer species on fresh landslides and abandoned land. It prefers a moisture-rich environment and grows mostly on north facing slopes of Nepal's mid-hills, although it also grows on south facing slopes in high rainfall areas (Lamichhaney 1995). It is popular among farmers in the mid-hills of Nepal as shade trees in farmlands and is a source of fuel wood and timber, though low in quality.

Populus x euramericana cv I-214 (Salicaceae; common name; poplar) is a female clone of a cultivated hybrid derived from *P. nigra* (a Mediterranean species) and *P. deltoides* (a North American species). It was developed in Italy and

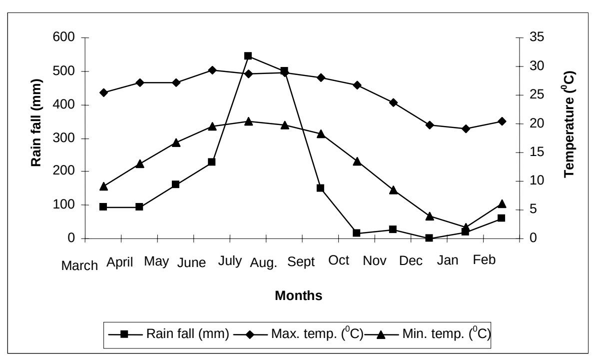

Fig. 1. Climate data for Kathmandu, March 2002 to February 2003 (Source: Dept. of Hydrology and Meteorology, Kathmandu, Nepal). The data were recorded at Tribhuvan International Airport (27°42' N, 85°22' E, alt. 1336 m), which is about 5 km east of study site.

has been widely grown all over the world, except in the cold countries of northwest Europe (FAO 1979). It was introduced to Nepal in 1965 from Pakistan and has been grown in Kathmandu as an avenue tree (NEFTIB 1981). It has great adaptability and extremely rapid growth. This clone develops very big branches rapidly, often forming a dangerous fork, which can only be controlled by careful and timely pruning (NEFTIB 1981).

Phenological observations

Phenological activities were observed every month at the time of wood sampling, but every two weeks during the period of active growth. Timing of bud swelling, bud break, flowering and leaf fall were recorded. The growth stage of leaves (i.e. expanding, mature or senescing) at the time of wood sampling was also recorded. Appearance of any specific phase in 10% of total trees was considered as the beginning of that phase. We examined phenophases in all the trees of the plantation stands; there were 30 – 35 trees of chir pine and poplar, and about 60 trees of alder.

Wood properties

Wood samples were collected monthly from March 2002 to February 2003. Ten individual trees of each species were randomly selected for sample collection, not necessarily the same tree in each month. From each tree a single wood sample (diameter 5 mm, length 35 to 55 mm) was collected from breast height (137 cm) using an increment borer. Wood was collected during midday (1200 to 1400 h). After the bark was removed from the sample, it was wrapped in aluminum foil, packed in an airtight plastic bag and placed in the shade to protect from direct sun light. Within one hour of collection, sample fresh mass was taken to 0.001 g. After the measurement of length, each sample was placed separately in a plastic tube with distilled water for 24 h to determine its saturated mass. It was oven dried for 24 h at 80°C to obtain dry mass. Volume of each wood sample was calculated from its measured length and the diameter of the increment borer. Then wood water content (WWC= 100 (fresh mass – dry mass)/ fresh mass), wood saturated water content (WSWC= 100 (saturated mass – dry mass)/ dry mass), and density (D_w = dry mass/fresh volume) were calculated following Borchert (1994).

Statistical analysis

Analysis of variance (ANOVA) was used to compare annual mean of three species and monthly mean within each species in their WWC, WSWC and D_w. Monthly mean of WWC, WSWC and D_w within each species were also compared using Multiple Range test. Regression analysis was used to study the relation between WSWC and D_w. Correlation coefficients were determined between pairs of species for WWC, WSWC and D_w, and also between these wood attributes and climatic data (rain fall and temperature) to determine the possible factor responsible for variation of these wood characters. SPSS 11.0 for Windows (2001) was used for statistical analysis.

Results

Phenology

Pinus roxburghii (chir pine): Winter buds appeared at the apex of twig in late October. They rapidly enlarged after late December, which coincided with the beginning of leaf senescence. Chir first produced buds of male cones in December, which matured in March. Vegetative buds for dwarf shoots appeared in early March and leaves (needles) appeared in late March (Table 1).

Table 1. Phenological activities of study species during each sampling date: bud break (B_b), leaf expansion (L_e), leaf fall (L_f), flowering (F), fruiting (F_r) and leafless (L_l).

Months	Chir pine	Alder	Poplar
2002			
Mar	B_b L_e L_f F	B_b L_e L_f	B_b L_e F
Apr	L_e L_f	L_e	L_e
May	L_e L_f	L_e	L_e
Jun	L_e	L_e	
July		L_e	
Aug		L_e	
Sep	B_b L_e	L_e	L_f
Oct		L_e F	L_f
Nov		F	L_f
Dec	B_b	L_f F_r	L_l
2003			
Jan	B_b L_f	L_f	L_l
Feb	B_b L_f F	L_f	L_l

Leaf elongation continued until June. Some trees in dry, sunny areas produced a second crop of leaves in 10-15% of terminal branches in mid-September, at the end of the rainy season. Leaf senescence began in December and leaf fall was completed by the second week of May. Life span of chir pine leaves was about 13 months.

Alnus nepalensis (alder): Winter buds broke in early March and shoot elongation and leaf production continued until October (Table 1). Leaf fall began in December and was completed in mid-March. Leaf life span is about 10 months. The plant in this habitat is not completely deciduous. The leaf area of alder was lowest in March with a few senescing leaves remaining at the tree top. Floral buds appeared in May. Male flowers matured in November and male inflorescences began to fall shortly threreafter. The fruit matured in December but was retained by the tree for about nine months, until August of the next year.

Populus x euramericana (poplar): Winter buds broke in mid-March. Leaf production and expansion was completed by late May (Table 1) therefore, it had mature leaves throughout monsoon. Leaf fall began in early September and was completed in early November. Trees were completely leafless for about four months from mid-November to mid-March and the average leaf lifespan was about 7 months. At the same time as new leaf production, poplar also produced flowers. Abscised inflorescence axes were seen on the ground during late April.

Table 2. Annual means (± standard deviation SD) of wood water content (WWC), wood saturation water content (WSWC) and wood density (D_w). Mean values of each parameter were compared among the species using multiple range test; the values followed by the same letter are not significantly different (α = 0.05).

Tree species	WWC (%)	WSWC (%)	D_w (g cm^{-3})
Chir pine	42.1±2.43a	105.6±9.5a	0.57±0.034c
Alder	43.1±3.58a	115.7±11.4a	0.47±0.017b
Poplar	53.4±5.32b	191.8±13.1b	0.36±0.014a

Wood properties

Annual mean values of wood attributes are given in Table 2 and monthly mean values are given in Table 3. The annual mean value of WWC was lowest in chir and highest in poplar (Table 2). In chir, monthly mean of WWC reached its highest value in April (46.2 %, Fig. 2). The monthly mean of WWC was highest during March (51%) in alder. Poplar had its highest monthly mean of WWC in January (59%) and lowest in late October (45.3%). The annual mean value of WSWC was also lowest for chir and highest for poplar (Table 2). Highest monthly mean values were measured in April for chir (125%), March for alder (132%) and July for poplar (211%) (Fig. 3). Chir pine had the highest annual mean D_w while it was lowest in poplar (Table 2). All three species had highest monthly mean D_w during late October (Table 3, Fig. 4). There was significant (ANOVA, $p<0.05$) difference in mean values of WWC, WSWC and D_w among

Table 3. Monthly means of wood water content (WWC), wood saturated water content (WSWC) and wood density (D_w). Each value was mean of ten trees. Monthly means of each parameter of each species were compared using multiple range test; the values followed by the same letter are not significantly different (α = 0.05). Highest values in each column are shown in bold face. E = early, L = late.

Months	Chir pine			Alder			Poplar		
	WWC (%)	WSWC (%)	Dw (g cm^{-3})	WWC (%)	WSWC (%)	Dw (g cm^{-3})	WWC (%)	WSWC (%)	Dw (g cm^{-3})
Mar	44.5bc	112.3def	0.53ab	51.01d	132.0e	0.45a	55.3cd	189.6bcd	0.35ab
Apr	46.2c	125.0f	0.51a	45.3c	113.0bcd	0.45a	51.3abc	200.3cde	0.35ab
May	44.2bc	108.8bcdef	0.59bc	44.0bc	118.3cd	0.46abc	47.9ab	197.1cde	0.35abc
Jun	43.8bc	111.7cdef	0.56ab	41.5abc	123.7de	0.47abcd	48.1ab	205.8de	0.36abc
Jul	41.4abc	99.8abcd	0.58bc	43.4bc	121.2de	0.47abcd	52.8abcd	211.5e	0.34a
Aug	-	-	-	39.6abc	107.8bc	0.49cd	48.1a	184.0bc	0.37abc
E Oct	42.3abc	120.5ef	0.54ab	43.0bc	107.2bc	0.46abc	55.6cd	192.6bcde	0.36abc
L Oct	37.3a	94.8ab	0.62c	38.8ab	106.6bc	0.51d	45.3a	173.9ab	0.39c
Nov	40.4abc	95.6abc	0.57abc	45.1c	114.6bcd	0.46abc	57.0cd	187.0bcd	0.36abc
Dec	39.2ab	88.7a	0.62c	36.6a	85.3a	0.49bcd	53.5bcd	163.8a	0.38bc
Jan	41.9abc	113.2def	0.55ab	44.3bc	122.6de	0.45ab	59.0d	208.0de	0.35ab
Feb	41.8abc	107.8bcde	0.60bc	44.5bc	122.9de	0.47abcd	57.0cd	189.7bcd	0.35ab

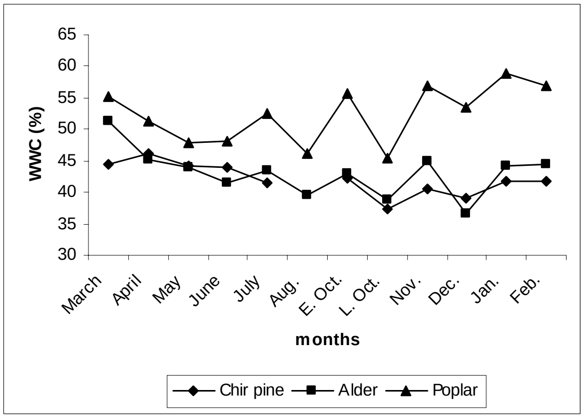

Fig. 2. Mean wood water content (WWC, %) of three species. Each value is the average of 10 samples.

the months for all three species. Poplar was significantly different from other species in WWC and WSWC while all three species were significantly different to each other in D_w (Multiple Range test, $\alpha = 0.05$, Table 2). The D_w had a reciprocal relationship with WWC and WSWC ($r = -0.79$ and -0.90, respectively). Species with high D_w had low WSWC (Fig. 5), and the relation was highly significant ($R = 0.91$, $p < 0.001$). The relation was also significant for the individual species (chir pine $R = 0.8$, $p = 0.003$; alder $R = 0.64$, $p = 0.025$; poplar $R = 0.81$, $p = 0.001$).

There was a significant correlation only between alder and chir in WWC, but the correlation was significant between all pairs of species for WSWC and D_w (Table 4). Correlation

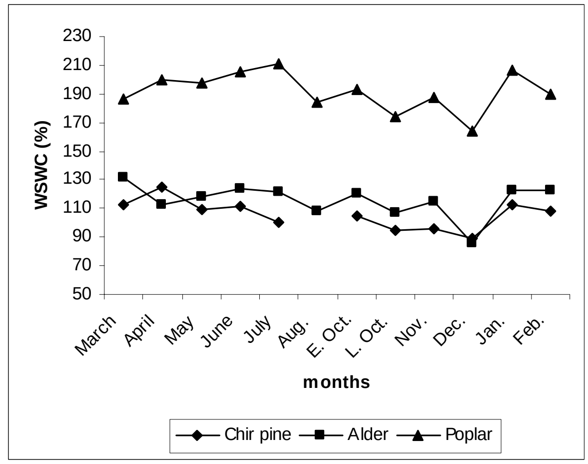

Fig. 3. Mean wood water storage capacity (WSWC, %) of three species. Each value is the average of 10 samples.

between wood properties and climate variables was not significant (not shown) except for poplar. The correlation between WWC of poplar and maximum and minimum temperature were significant at $p = 0.05$ ($r = -0.67$ for both).

Discussion

Chir pine is an evergreen species with leaf life span of 13 months. It is unusual in having such a short leaf longevity; it is the only pine with leaf longevity <1.5 years (Richardson & Rundel 1998). Alder and poplar both are broadleaved tree species. Leaf production and expansion were

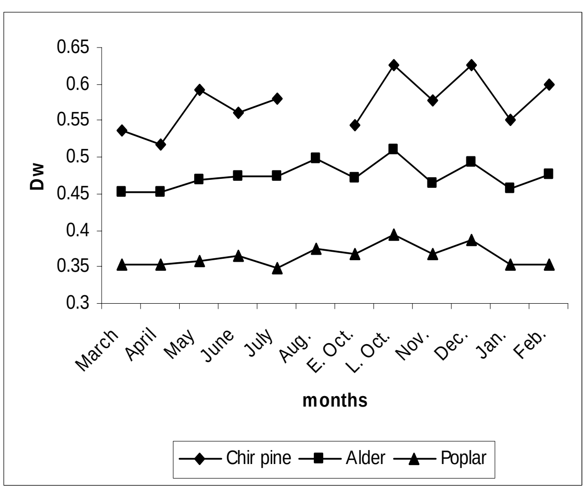

Fig. 4. Mean wood density (D_w, gm^{-2}) for three species. Each value is the average of 10 samples.

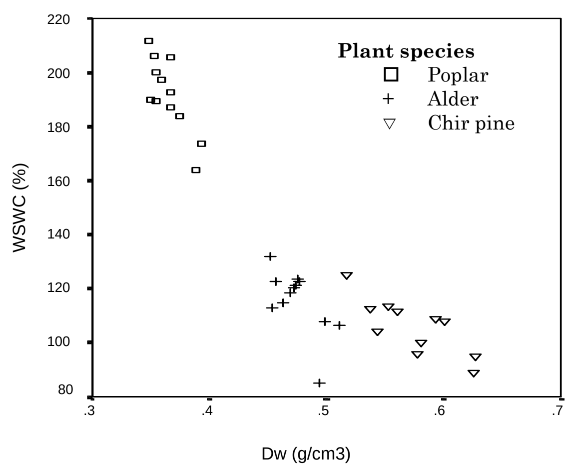

Fig. 5. Relationship between D_w ($g\ cm^{-3}$) and WSWC (%) of three species. Each value is a monthly mean of 10 trees. $R = 0.91$, $p < 0.001$.

Table 4. Pearson correlation coefficient (r) between pairs of species in monthly mean of WWC, WSWC and D_w. The sample size was 12 for alder and poplar and 11 for chir pine.

Tree species		Attributes		
		WWC	WSWC	D_w
Chir pine	Alder	0.66*	0.60*	0.78*
	Poplar	ns	0.64*	ns
Alder	Poplar	ns	0.74**	0.84**

*significant at P = 0.05
**significant at P = 0.01
ns- non-significant

completed in < 3 months in poplar; and it had all mature leaves during rainy season (Table 1). But, in alder leaf production and expansion continued for eight months from March to October. Leaves of alder were heavily damaged by insect herbivory but it was not observed in poplar. Defoliation was mainly by insect larvae of family Chrysomelidae, Cryptocephalidae and Scarabaeidae (Lamichhaney 1995). Therefore, prolonged period of leaf production in alder may be associated, at least partly, with reduction in leaf area due to insect herbivory. In both broadleaved species (alder and poplar), significant reduction in WWC (Fig. 2, Table 3) might have induced leaf fall (Table 1).

There was a close relation between leaf area in a tree species and WWC. In chir and alder, concentrated leaf fall during March-April reduced transpirational water loss and could help to rehydrate the tissue (Shrestha *et al.* 2006). In present study WWC was measured highest during April for chir and March for alder (Fig. 2, Table 3). These two species had similar values of WWC (Table 2). The water stored in the stem may be used for bud break and new leaf growth during March-April. New leaves increased transpiring surface of a tree and water loss, which reduced WWC after those months (Fig. 2). WWC of chir was most stable (i.e. small SD) among these three species (Table 2). Similar stable stem water content was also reported for *Pinus contorta* (Running 1980) in the Rocky Mountains (Colorado, USA). Therefore, water requirement for new growth during dry period seems to be contributed largely by water conserved due to leaf fall. Chir pine growing naturally in Churia hill of central Nepal also showed similar features (Shrestha *et al.* 2006). Earlier leaf senescence in trees of dry sites than in wet was also reported in Churia hill.

Leaves of poplar were shed rapidly during the early dry months (September-October) (Table 1). It has a shallow root system with horizontal surface roots (length 15-20 m) from which develop deep vertical roots (FAO 1979). Soon after the rainy season, surface soil moisture is depleted, which decreases the water supply to the tree. Being a hygrophilous species with high water demand (FAO 1979) poplar quickly responded by leaf fall to the cessation of the monsoon and soil water depletion.

From March to June, WWC was continuously decreasing in poplar (Fig. 2). Water used for leaves and stem growth depleted the water stored in the tree trunk. During the period of vegetative growth (March to July) WSWC was continuously increasing (Fig. 3). During this period the freshly formed wood contributed to the high water storage capacity; it also has maximum moisture content (FAO 1979). There was very little increase in density (0.35 to 0.36 g cm^{-3}) during this period (Fig. 4).

Poplar is a light demanding and a fast growing tree species but has very short leaf life span. Plants with high WSWC can continue photosynthesis at normal rate for additional hours everyday (Kramer & Boyer 1995) and have high maximum photosynthetic rates (Stratton *et al.* 2000). Poplar had the highest variation in WWC and WSWC (Table 2), which also indicates the significant contribution of stored water to meet the water requirement, particularly during dry months. Photosynthetic rate of poplar was reported from 0.15 to 0.25 mg h^{-1} m^{-2} of leaf surface, which is among the highest values measured for trees (FAO 1979). There is a trade off relation between leaf life span and maximum photosynthetic rate; with decreasing leaf life span maximum photosynthetic rate increases (Kikuzawa 1995; Lambers *et al.* 1998). All studied species bear the cost of annual leaf production, but the cost is highest for chir, as it has a thick leaf (Reich *et al.* 1997); this would reduce net productivity of the plant. Alder and poplar were broadleaved species with a thin leaf and high photosynthetic rate; they are early successional species (Jackson 1994) and have high relative growth rate.

A distinct pattern of change in wood properties and leaf phenology can be observed in these three species. With decreasing leaf life span from chir (13 months) to alder (10 months) to poplar (7 months), D_w decreased, and WWC and WSWC increased (Tables 1& 2). Wood with low D_w had high WSWC (Fig. 5), and the relation was highly significant ($R = 0.91$, $p < 0.001$). This relation was also significant for individual species too. It is worth noting that pine had greater D_w for the same WSWC than alder. Presence of very small amount of axial parenchyma in pine wood (Esau 1965) might have contributed to higher D_w. This also supported the previous observation that water stored in wood of chir pine is an important source of supply for new growth during dry summer (Shrestha *et al.* 2006). The three species were significantly different in D_w (Table 2). It appears to be the reflection of their different natural habitat. Chir pine is common on dry, south facing slopes of the hills (Jackson 1994); alder on moisture rich north facing slopes (Lamichhaney 1995); and poplar has been grown on valley plains (NEFTIB 1981). D_w of alder (0.319 g cm^{-3}) reported by Lamichhaney (1995) was not within the range of present values (av. 0.47 g cm^{-3}, range: 0.45-0.51 g cm^{-3}). But the value (av. 0.47 g cm^{-3} range 0.44-0.57 g cm^{-3}) reported by Uprety (2002) from different stands of Kirtipur (Kathmandu) is same as the present value. The very low value reported Lamichhaney (1995) may be either due to the difference in methods of volume measurement or to the site-specific variation. D_w of poplar (0.36 g cm^{-3}) was comparable to the range (0.32-0.44 g cm^{-3}) reported by FAO (1979). Present value is less than the average (0.4 g cm^{-3} range: 0.34-0.44 g cm^{-3} of 18 different clones of *Populus deltoides* (which is one of the parent of *P. x euramericana*) (Chauhan *et al.* 2001).

Since correlation was highest for D_w (Table 4) among the species, it seems that some common factors are responsible for its monthly variation (Table 3). The correlation of density with climatic factors was not significant. Since the climatic data alone are not sufficient to explain the plant traits such as tree phenology of seasonally dry tropical forest (Borchert 1994), it may also be true for D_w. A possible environmental factor that affects D_w is soil moisture, but it was not measured. Soil moisture at rooting depth appears to be an important factor as it does not vary directly with climate. Measurement of leaf life span, D_w, WSWC, and soil moisture in natural forest help in understanding the relationship between foliar phenology, wood properties and soil variables. Studies related to functional wood anatomy of tree species may help to understand the rehydration processes in species showing variable durations of deciduousness (Singh & Kushwaha 2005).

Conclusions

Among the three species studied, *Pinus roxburghii* (chir) and *Populus x euramericana* (poplar) have concentrated leaf production and leaf fall, while in *Alnus nepalensis* (alder) leaf production continued from March to October. *P. roxburghii* and *A. nepalensis* retained mature leaves during dry winter and early summer while *P. x euramericana* was leafless during that period. Chir pine is unusual in having very short (only 13 months) leaf life span. Despite their unequal leaf life span, production of new leaves took place simultaneously in all species during March, a dry month. All these species were phenologically most active during March. With decreasing leaf life span and D_w from *P. roxburghii* to *A. nepalensis* to *P. x euramericana*, the WWC and WSWC also decreased; the relation between D_w and WSWC was significant. These three species were significantly different in their D_w. Since all trees were phenologically active during summer (February to May), which was the driest period (based on the climatic variables) of the year, the climatic variables alone could not explain the phenological pattern of these trees. Water conserved by reduction in transpirational water loss due to leaf fall appears to be an important source of water for new leaf production during the dry summer (March-April).

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