ENVIRONMENTAL FACTORS AFFECTING RADIAL GROWTH IN AFFORESTATIONS NEAR TIMBERLINE

H. Turner and W. Schönenberger

Section Forest and Environment
Swiss Federal Institute of Forestry Research
CH-8903 Birmensdorf
Switzerland

SUMMARY

Radial tree growth in 12-15 years old plantations of larch, mountain pine, spruce (and Swiss stone pine) was investigated near the timber line in the Stillberg experimental area (Dischma valley near Davos, Switzerland). Radial growth as judged by stem diameters at different sites turned out to be strongly affected by the same decisive factors as was found previously for shoot elongation. Increasing slope irradiation, increasing soil temperature and decreasing wind speed have strong positive effects on radial growth especially of larch and mountain pine, whereas spruce was more strongly affected by date of snow melt and wind speed.

Low September temperatures resulted in distinct setbacks of larch ring width in the following year, especially on the cool N-facing slopes. Peaks of annual increment are found in years following a warm, favourable autumn, provided that the weather of the current summer does not limit growth.

ZUSAMMENFASSUNG

Das Dickenwachstum in 12-15 Jahre alten Hochlagenaufforstungen (Lärche, Spirke, Zirbelkiefer und Fichte) wurde im Versuchsgelände Stillberg an der oberen Waldgrenze des Dischmatales bei Davos (Schweiz) untersucht. Beurteilt nach dem Durchmesser der Stämmchen erwies sich das durchschnittliche jährliche Dickenwachstum auf den verschiedenen Standorten stark durch dieselben entscheidenden Umweltfaktoren beeinflusst, wie für das Höhenwachstum der gleichen Aufforstungen gefunden wurde. Eine deutliche Zunahme der Durchmesser ergibt sich namentlich mit zunehmender durchschnittlicher Hangbestrahlung und Bodentemperatur während der Vegetationszeit sowie mit abnehmender Windexposition der Standorte. Dies gilt insbesondere für Lärche und Aufrechte Bergföhre, während bei der Fichte die Einflüsse des Ausaperungsdatums und der Windexposition im Vordergrund stehen.

Bezüglich Jahrring-Breiten wirken sich (bei Lärche) niedrige September-Temperaturmittel in deutlicher Jahrring-Verengung im folgenden Jahr aus, ganz besonders an kühlen Nordhängen. Maximalwerte des jährlichen Dickenzuwachses hingegen ergeben sich in Jahren, die einem Herbst mit warmer, günstiger Witterung folgen, vorausgesetzt, dass die Sommerwitterung des Referenz-Jahres nicht wachstumsbegrenzend wirkt.

1. INTRODUCTION

This investigation is part of the subalpine research program of the Swiss Federal Institute of Forestry Research which can be outlined by the following topics:

1. Experimental plantations of suitable tree species and provenances up to the Alpine timberline using several techniques of planting and site melioration.
2. Investigations into the spatial distribution as well as temporal sequence of important environmental factors within the afforestation areas.
3. Investigations into the response of the planted young trees to the environment,
   - by recording the gas exchange and ambient environmental conditions of selected trees in the field at intervals of 3 minutes by means of climate-controlled Koch-Walz-cuvettes, at different sites,
   by phenometric measurements of longitudinal root and terminal shoot increment in weekly intervals at different sites where microclimate is recorded,
   finally by year to year observations of survival, kind and extent of damages,and growth in the afforestations, and relating these data to the environment by means of ecological maps, scale 1:500, showing the distribution of environmental factors common to the topography.

2. MATERIAL, METHODS

Radial growth in high altitude afforestations was studied at various sites of the Stillberg experimental area (2000 - 2230 m a.s.l.) which represents an active avalanche release zone on a steep NE-slope (inclination 40 degrees) in the Dischma valley near Davos. Basal stem diameter measurements of 1019 young trees (*Larix decidua, Picea abies* and *Pinus montana arborea*) were carried out in the year 1974 (= 15 years after planting). Further radial growth data could be obtained by means of stem disc evaluations after earning 300 trees (*Pinus cembra* and the other above mentioned species). Stem discs (of larch only) could be used to measure the areas of the individual tree rings. This resulted in exact data of real ring-width which could not otherwise be obtained for most tree ring patterns in the high altitude afforestations are very eccentric due to severe mechanical stress by downslope snow pressure.

Methods of relating growth data to environmental factors are described by Turner (1971) and Schönenberger (1975). Also more detailed information on the test plantings and on environmental data of the experimental area is provided in these previous papers. In the present paper some preliminary results concerning the hitherto not published radial growth data are shown.

3. RESULTS

In general the correlations between radial growth data and spatial variations of site factors show similar relationships as were obtained with respect to environmental influences upon longitudinal shoot growth (Turner 1971, 1976; Turner et al. 1975; Schönenberger 1975, 1976). Figure 1 represents a typical growth model showing mean annual shoot increments of larch dependent upon the two primary and independent micro-climatic variables insolation and wind speed. This coincidence is due to the fact that correlation between stem heights and stem diameters is relatively close; these correlation coefficients

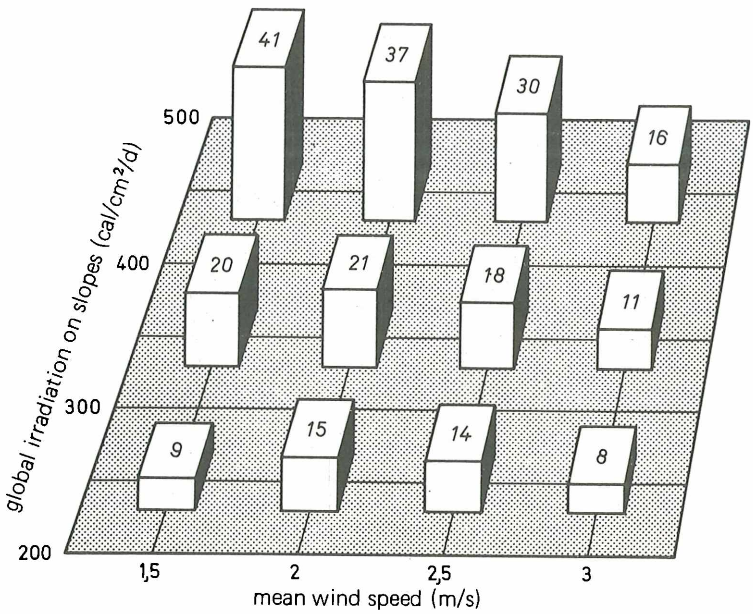

Fig. 1: Growth of larches (*Larix decidua*) as affected by mean wind speed (during day-time of the snowfree season June - September, 1 m above ground) and by global slope irradiation (with clear skies, mean daily sums during growing season June - September) in the subalpine Stillberg research area (2050 - 2180 m a.s.l), represented by mean annual height increments (mm) in nine-years-old plantations (1959 - 1968) at various sites. (After Turner 1971 from Turner 1976.)

are as follows: 0.84 (*Larix decidua*), 0.86 (*Pinus montana arborea*) and 0.81 (*Picea abies*) [average values over all sites].

In addition to the data in Fig. 1 the following main results of previous investigations can be given:

1. High wind speed on the ridge is a limiting factor for height growth, but not for survival.
2. Low temperature and low radiation on the N-slope reduce both survival and height growth of the surviving trees.
3. High competitive power of the vegetation in the gully is a limiting factor for survival, but permits satisfying height growth of the few surviving trees.

Table 1 shows that insolation, mean wind speed and mean soil temperatures during the growing season exert a distinctive influence on radial growth of larch and mountain pine: basal stem diameters are about twice to three times greater on sites which receive relatively high insolation and low wind speeds and which have on an average 3°C warmer soils than the unfavourable shaded and wind exposed sites. The sites having moderate dates of snow melt (about mid-May) tend to produce relatively high stem radial growth rates when compared with growth on sites showing earlier or later snow melt. Spruce was planted obviously above the upper natural limit of its distribution; climate stress is extremely severe at all sites, so that correlation of stem diameters to insolation and soil temperature is less close; wind speed and date of snow melt seem to be more decisive for spruce radial growth at these high elevated sites than insolation and soil temperature.

It can be demonstrated that the very different growth rates of larch, mountain pine (and Swiss stone pine) according to the described microclimatic differences are reflected by similar differences in photosynthetic capacity. Typical daily courses of net photosynthesis in larch on the warm E-facing slope and on the cool N-facing slope are shown in Fig. 2. It is revealed that carbon dioxide gain (per unit dryweight of the needles) is twice to three times as high on the E-slope than on the N-slope. More detailed results of the investigations into the dry matter production in high altitude afforestations will be published by Häsler.

Investigations into the influence of different site conditions as well as of different weather conditions from year to year upon ring width of young trees of larch in the "Bermen" plantation of 1962 gave the following results (Table 2, Fig. 3):

1. On warm (sunny) E-facing slopes larch generally shows annual radial increments of 0.8 mm; this is twice as high as on N-facing slopes which have 3-4°C lower soil temperatures and less than half of slope irradiation in summer.

2. On strongly wind-exposed sites (3 m/s) which in summer are as cool as the N-facing slopes but receive higher irradiation, annual increment within the first 10 years after planting is intermediate between E- and N-slopes, but finally

Table 1: Mean basal stem diameters (mm) of young trees 15 years after planting, related to spatial variations of insolation (global slope irradiation with clear skies), wind speed at 1 m above ground, soil temperature at 6 cm depth (mean values during growing season June - September), and average date of snow melt (1960-1970). 40 pairs of values per factor and tree species. (The figures in the table are derived from regression lines.) (Stillberg site testing plantations 1959.)

		Larch *(Larix decidua)*	Mountain Pine *(Pinus montana arborea)*	Spruce *(Picea abies)*
Insolation ($kcal\ cm^{-2}$)	37–50	14	8	8
	51–64	21	14	10
	65–78	27	21	12
		r = 0.55	*r = 0.64*	*r = 0.18*
Wind speed (m/s)	1.3–2.0	23	16	11
	2.0–2.7	19	12	9
	2.7–3.4	15	8	7
		r = –0.46	*r = –0.52*	*r = –0.48*
Soil temperature (°C e T)	6.4– 7.8	15	9	9
	7.9– 9.3	22	15	11
	9.4–10.8	28	21	13
Date of snow melt	Apr. 22–May 7	22	17	11
	May 8–May 23	24	16	12
	May 24–June 8	17	10	8
		r = –0.21	*r = –0.24*	*r = –0.32*

Table 2: Mean annual ring width of larch (*Larix decidua*) in the "Bermen" plantation of 1962 at three different sites

	E-slope	N-slope	ridge (NE-exposed)
Insolation kcal cm^{-2} (growing season)	80	20	60
Wind speed 1 m above ground m/s (growing season)	1.5	1.5	3.0
Mean soil surface temperature °C e T (growing season)	20	10	14
Mean soil temperature 10 cm warmest month (July) °C	11	7.5	8
Mean annual real ring width 1964-1974 mm	0.8	0.4	0.6 – 0.8

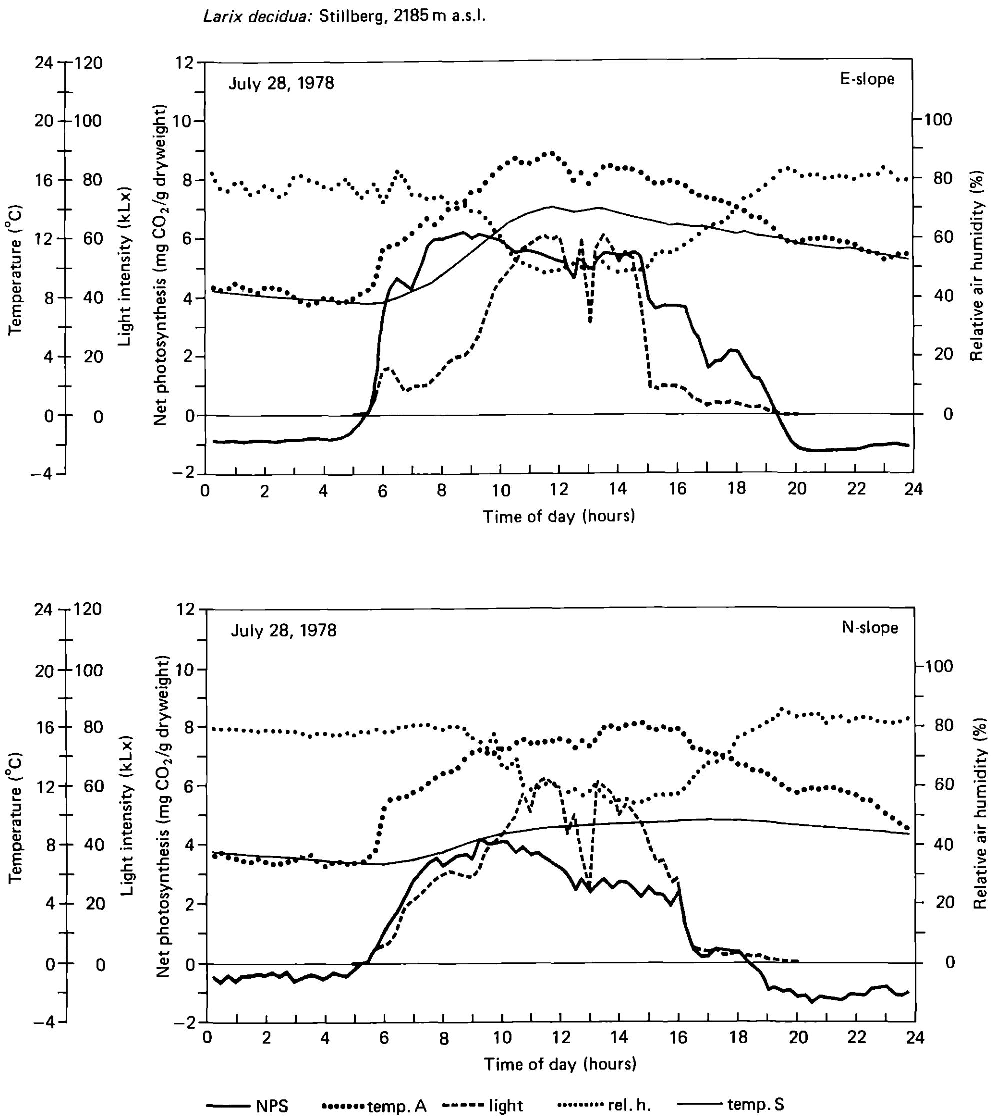

Fig. 2: Typical site differences of dry matter production in high altitude afforestations, represented by the diurnal courses of net photosynthesis (mg CO_2 per g dryweight of needles) in young larches (*Larix decidua*) and of ambient weather conditions on an E-slope (above) and on a N-slope (below) of the Stillberg research area (2185 m a.s.l.).
NPS = rate of net photosynthesis; temp. A = air temperature; light = light intensity, level of illumination; rel. h. = relative air humidity; temp. S = soil temperature at 3 cm depth. (From Häsler & Blaser 1981, modified).

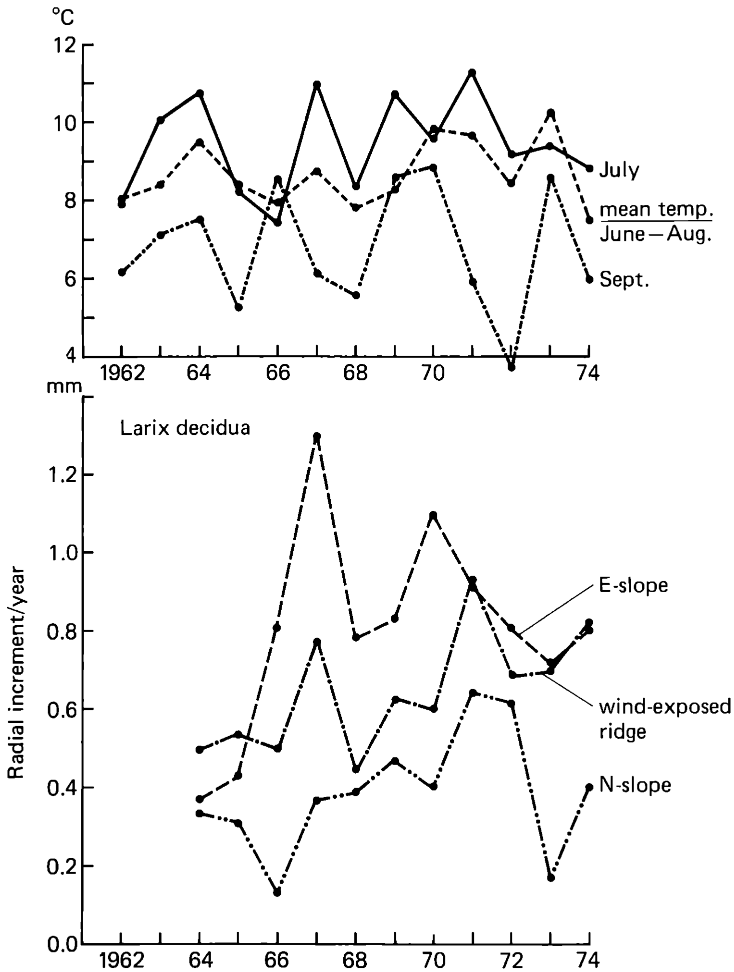

Fig. 3: Below: Annual real ring width (not standardized, derived from growth ring area measurements) of young larches (*Larix decidua*) at three typical sites of the subalpine Stillberg research area (2180 m a.s.l.), each curve representing mean values of 8 - 10 individual trees which were planted 1962 and earned 1975.
Above: Mean monthly values of air temperature, measured at the meteorological station Stillberg-Alp (2000 m a.s.l.).

after that period of settling, annual increments are as high as on the warm slopes, presumably when the young trees are adapted to the windy environment.

3. Peaks of annual increment preferably occur in years following a warm favourable autumn if summer weather of the

current year is at least moderate (years 1967 & 1970). This is true for all three discussed sites. [An exception of this rule is 1971 when we would have expected a larger annual increment on the E-slope.]

4. Distinct setbacks of ring width from the general trend only did occur on the cool N-facing slope, preferably in years following a bad autumn of the previous year and when summer weather of the current year is average or bad.

4. DISCUSSION

From the present state of ecophysiology of trees at high elevations (Tranquillini 1979) it seems not quite clear why autumn weather (e.g. mean September-temperature) has such distinct influences on dry matter production and larch ring-width of the following year (see also Frenzel, this volume, with respect to Swiss stone pine). Obviously the duration of photosynthetically active leaf area of larch is greatly dependent upon autumn weather. We can also observe each year that growth processes in the shoots of larch last as long as weather is permitting, and that there are great differences with this respect from year to year and from one type of site to another. But we have no observations up to now on effects of autumn weather on the partitioning, translocations, storage a.s.o. of photosynthates, carbohydrates and other organic compounds. It is also unknown what transformations take place in winter and spring before cambial growth is activated. It is reserved to further ecophysiological studies to expand and deepen our knowledge with respect to these processes.

It is, on the other hand, well known (Tranquillini 1979) that bad autumn weather may be a main factor in prohibiting maturation of tissues, resulting in inadequate climatic resistance (e.g. against desiccation) during the following winter. Unfortunately larch is insufficiently investigated with this respect. It may also be pointed out that the small trees of our trial afforestations are generally well protected against winter desiccation by the snow cover. It will be therefore the next step in our investigation to examine if there is any close interrelationship between occurrence of certain kinds of damage to the trees, rate of shoot elongation (shoot die-back respectively), accurate courses of weather conditions and of plant gas exchange, and annual ring width.

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