From Forest Nursery Notes, Winter 2011

10. Prediction of height development in first-year Norway spruce (*Picea abies* (L.) Karsten) container seedlings in a nursery. Rikala, R. and Lappi, J. Baltic Forestry 16(1):43-49. 2010.

Prediction of Height Development in First-year Norway Spruce (*Picea abies* (L.) Karsten) Container Seedlings in a Nursery

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Rikala, R. and Lappi, J. 2010. Prediction of Height Development in First-year Norway Spruce (*Picea abies* (L.) Karsten) Container Seedlings in a Nursery. *Baltic Forestry*, 16 (1): 43-49.

Abstract

Most nurseries measure and document records of the environmental conditions and growth variables of seedling crops. The usefulness of this operationally collected data for crop scheduling and predicting seedling height has not been studied. We used operational 10 years' data (information of growing measures of seedling batches, daily mean temperature and photoperiod, weekly monitored electrical conductivity and water content of growing medium) of commercially grown first-year container Norway spruce (*Picea abies* (L.) Karsten) seedling batches to predict height development of seedling batches. Our data did not support the idea that the termination of height growth could be predicted accurately on the basis of photoperiod and temperature sum in operational seedling production. The best indicator for the final height was the sowing date. Although the measured variables, especially average weekly nitrogen given, correlated with the final height of seedlings, these variables did not give any additional explanation to sowing date. Within seedling batches the germling height (height of seedling at the age of 5-6 weeks) did not predict well the final height of seedlings.

Key words: fertilization; growth rhythm; sigmoidal function; photoperiod, sowing date; temperature sum

Introduction

Need to extend the planting window as well as positive results of summer plantings (e.g. Luoranen et al. 2006, Tan 2007) will increase seedling production for whole season planting. Growing target seedlings for certain planting date emphasize the need to predict and control seedling growth in nursery production more exactly. This requires better knowledge of the effects of sowing dates and timing of cultural measures on seedling development.

Seedling height is one of the most common characteristics used to define seedling crops to be marketed (Mohammed 1997) and it is also simplest measurable attribute to monitor seedling development in the nursery. Timing of height growth cessation in first-year spruce seedlings has been explained by the joint effect of photoperiod and temperature sum accumulation (Heide 1974, Koski and Sievänen 1985, Partanen 2004). Through the effect of photoperiod also seed origin used affect growth cessation. In addition fertilization is shown to affect growth cessation of seedlings (Macey and Arnott 1986, Hansen 1992, Bigras et al. 1996) and seedling height (Driessche 1980, Thompson 1995). Also moisture stress has been observed to induce growth cessation and bud set in *Picea glauca* (Moench) Voss seedlings (Macey and Arnott 1986) while in western larch seedlings it has no effect (Vance and Running 1985). Thus final height of seedlings should be able to be predicted with date of sowing, time of growth cessation determined by "photoperiod-temperature sum-model", fertilization and irrigation.

Most of nurseries measure and document records of the environmental conditions and growth variables of seedling crops. This data over several crops and years could be valuable basis for crop scheduling not merely for decision-making for daily cultural measures. Therefore cultural records are suggested to provide also a plan for duplicating successful crops (Landis et al. 1995). Although the importance of accumulating records has been emphasized and a lot of data is apparently collected, the usefulness of this operationally collected data for crop scheduling has not been studied.

Cultural records considered important fall into three categories: growing schedules, environmental conditions in the propagation area and crop development records (Landis et al. 1995, p. 161). In Finnish nurseries, recordkeeping includes the timing of growing measures like sowing, fertilization, pesticide treatments, and culture-related records such as air temperature, electrical conductivity (EC) of peat water extract of root plug and the weight of seedling trays for estimating water content (WC) of growing medium. Crop development is usually monitored by weekly records of shoot height and visual observation of possible pest symptoms.

The aim of this study was to find out whether the operational data of commercially grown first-year container spruce seedling batches of a nursery can be utilized for predicting height development of seedling batches. The height prediction was done by estimating height curve for each seedling batch and then it was studied how the batch parameters can be predicted using measured variables.

Materials and methods

Climate conditions

The data of 29 commercially grown first-year Norway spruce (*Picea abies* (L.) Karsten) seedling batches were collected in Suonenjoki nursery in Central Finland (62° 39' N, 27° 03' E, 140 asl) in years 1995–2005. According to the long term weather data in year 1971–2000 the length of thermal growing season in Suonenjoki is 157 days from May 2 to October 5. The average daily mean temperature in July varies between 15–18°C. Temperature sum varies 1,100–1,250 d.d. (degree-day, threshold value +5°C). Photoperiod increases from about 15 h (15 Apr.) to maximum (20 hours) in 20 June and decreases again to 14 (5 Sept.).

Seedling material and measurements

Eighteen of total 29 seedling batches were purposed to be planted as one-year old (later called A-stock) and 11 batches were planned to be reared another year for two-year old seedling stock (later called B-stock). Seed for these seedling batches was obtained from registered seed orchards producing seed adapted to the conditions in Central Finland. The utilization area of the orchard seed is determined in Finland by the temperature sum of the region basing on the temperature sum of grafts and of the location of the seed orchard. In a seed lot (orchard), the range of utilization area is 200 d.d. (e.g. 1,100–1,300 d.d.). For the studied seedling batches they varied in 1,020–1,300 d. d. The same seed lots were used both A- and B-stock sowings. The sowing times for A-stock varied from 14 April to 11 May and for B-stock from 23 May to 16 June. In years 1995–2000 A-stock seedlings were kept in greenhouse from sowing to middle of October but since 2001 they were transferred to open compound in the middle of July. Short-day treatment was not used with the studied seedling batches.

In April and early May greenhouses were heated during cool periods targeting minimum temperature at least 10°C and mean temperature 15–20°C. In 1995-1998 the seedlings were grown in Ecopots (types PS508, PS608) (Lännen Oy, Säkylä, Finland) and in years 1996-2005 in Plantek containers (types PL121F, PL81F and PL64F; Lännen Oy). Growing densities varied depending on container type from 432 to 816 seedlings per square meter. Most of A-stock seedlings were grown at higher densities (smaller pots) and B-stock seedlings at lower densities (larger pots). Growing medium used was pre-fertilized (N16-P8-K16 and micronutrient) and limed light Sphagnum peat. In addition, all seedling batches were fertigated (Superex-fertilizers including NPK and micronutrients, Kekkilä Oy, Tuusula, Finland) 5–12 times in a summer. The aim was to maintain the water content of the peat medium at an optimum level (40–55%, v/v) by irrigating seedling trays to target weight. The fertigation aimed at keeping the electrical conductivity (EC) of the press water in the peat within recommended values (1–2 mS cm^{-1}).

Pre-fertilizer incorporated in growth medium included about 8–10 g of N m^{-2} depending on pot form and meaning 14–30 mg of N per container cell depending on the container volume. Average total amount of nitrogen given in fertigation was 9.9 g m^{-2} (range 5.3–22.6 g/m^2) and 3.2 (range 1.5–7.8) g m^{-2} for A- and B-stocks, respectively. The seedlings were irrigated with mobile irrigation booms. Container trays of A-stock were placed on plastic supports (height 8 cm) until the year 2000 and after that on pallets (height 20 cm). The trays of B-stock were kept on plastic pipes (diameter 1.5 cm).

The temperature was measured with thermohygrograph (Fuess) in the weather cabin in the open compound and with Pt100 sensor (HMP45A/D, Vaisala, Finland) in greenhouses. Weekly temperature averages and temperature sum (threshold +5 °C) from sowing to the end of shoot elongation for each seedling batch were calculated.

Shoot elongation of seedlings in each batch was monitored by measuring the shoot height (mm) from peat surface to tips of upper needles of sample seedlings. Five to 10 sample seedlings were randomly selected from 2 to 3 seedling trays for monitoring. The first measurement was done 6-7 weeks from sowing date and it was continued weekly to the end of shoot elongation. The measurement of some seedling batches were, however, finished before the elongation was totally ceased. Adjacent seedling trays (3 trays/batch) to the height monitoring trays were weighed weekly. One seedling from three extra trays was sampled for press extract of peat water for measuring electrical conductivity (EC) of water. In order to transform the weights of different container tray types to water content (WC, v/v) of peat, the weight of tray, dry peat, covering material and seedling weight were subtracted from the total weight of seedling tray and the result was divided by the container volume. Measured EC was transformed to correspond to the target water content (45%, v/v) of peat using the equation presented by Rikala and Heiskanen (1997).

Results

Description of environmental conditions and seedling material

Temperature sums for seedling batches including the growing periods of both greenhouse and open compound varied from 1,479 to 2,854 d.d. The average WC of peat during the shoot elongation was 47% (range 40–71%). The average EC of peat water extract 1.1 mS cm^{-1} (range 0.68–1.67 mS cm^{-1}).

The final mean height of seedling batches for A-stock was 19.2 cm (range 12.8–23.1 cm) and for B-stock 7.7 cm (6.2–10.3 cm) (Fig. 1a, b). Variation among individual seedlings within batches (Fig. 2a) was in average smaller for A-stock (average coefficient of variation 0.145) than for B-stock (0.200). This is likely due to less favorable germination conditions like high temperature and drought in late June than in April or May.

Germling height vs. final height

The height of germlings five to six weeks after sowing did not predict well the final height of seedlings at the end of growing season (Fig. 2b). Average coefficient of determination (R^2) for A-stock seedling batches was 0.232 and for B-stock 0.165. The average CV for the initial height in seedling batches was 0.12 and for the final height lower than 0.17.

Modeling of height development

The statistical analysis of the height development was done as follows. The height growth of each seedling lot was described using a sigmoidal function (see Ratkowsky 1990 p. 142):

$$H(t) = a - b\left[(a - H_1)/b\right]^{(t/t_1)^d} \qquad (1)$$

where t is time since sowing (in days), a is the upper limit, b is the range of heights, (a-b is thus the lower limit corresponding to the height of seedlings after early growth stage, see Landis et al. 1998, p 11). H_1 is an expected-value parameter corresponding the height at $t=t_1$ and parameter d determines how fast the curve approaches the upper and lower limit. The time of growth cessation is of special interest. Thus Eq. (1)

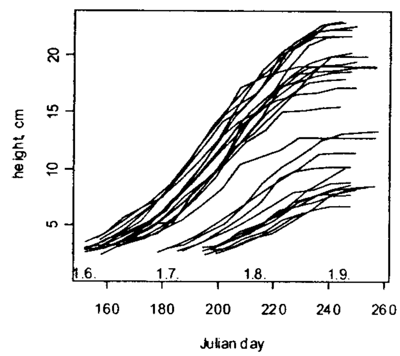

Figure 1a. The measured height as a function of the Julian day for the 29 seedling lots in the data (the dates are indicated above the x-axes)

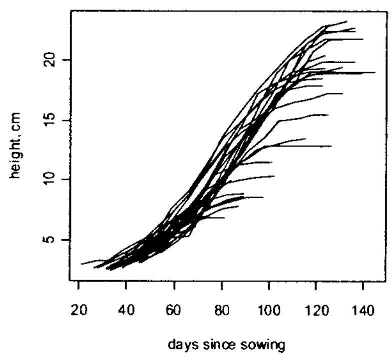

Figure 1b. The measured height as a function of the time since sowing

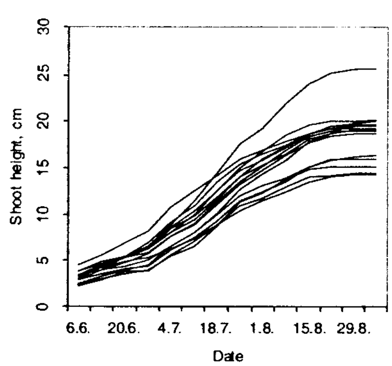

Figure2a. An example of the measured height of individual seedlings in a seedling batch (no 14: PL81F). Sowing time 5 May. The final height of the seedling batch was 20.3 cm and coefficient of variation was 0.16

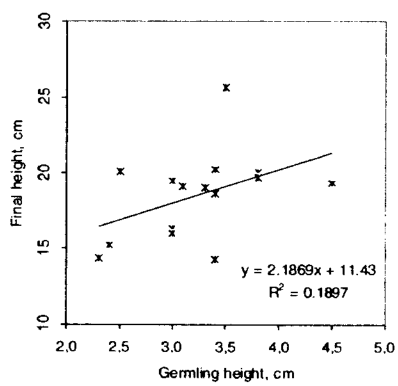

Figure 2b. The relationship between the germling height (height of seedlings 7 weeks after the seeding) and the final height (4 September) in batch no 14

was reparameterized by taking as a parameter the time when the height reaches 95% of the maximum height. This is accomplished by replacing H_l by 0.95 a and taking t_l as a parameter, i.e. using equation

$$H(t) = a - b[0.05a/b]^{(t/t_l)^d} \qquad (2)$$

Parameters a, b, t_l and d were estimated with nonlinear least squares for each lot.

The dependency of the estimated curves on the sowing time S was then described. The upper limit a was linearly dependent on the sowing time S (see Fig. 3), and it can be predicted with equation (standard errors in parenthesis, RMSE=1.95 and R2= 0.89):

$$a = 52.3 - 0.271\ S \qquad (3)$$
$$(2.4)\ (0.018)$$

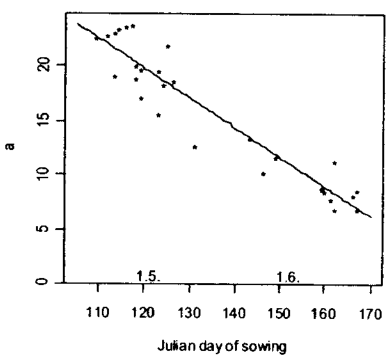

Figure 3. The estimated upper limit parameter a as a function of the time of sowing, and the estimated regression line (Eq.3)

The lower limit a-b did not show any significant dependency on S (Fig. 4). Thus a-b can be predicted using the average value 2.45 cm (standard deviation was 0.39, and standard error of the mean was 0.07 cm). After predicting a and a-b, the corresponding predictor of b can be computed by subtracting the predictor of a-b from the predictor of a. The reason for predicting a-b instead of b is that b has a high correlation with a and thus b shows trivially close dependency on S.

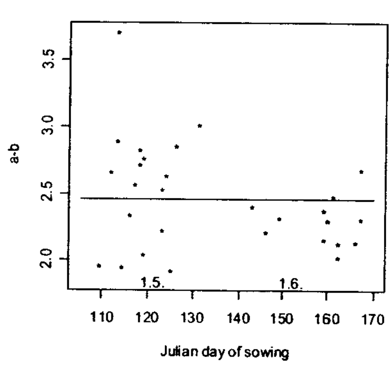

Figure 4. The estimated lower limit a-b as a function of the time of sowing. The horizontal line indicates the average. The outlying point is a lot for which there were no measurements during the initial phase of slow growing

Parameter d either did not show any significant dependency on S (Fig. 5). Thus d can be predicted with the average value 4.06 (standard deviation was 0.59, and standard error of the mean was 0.11).

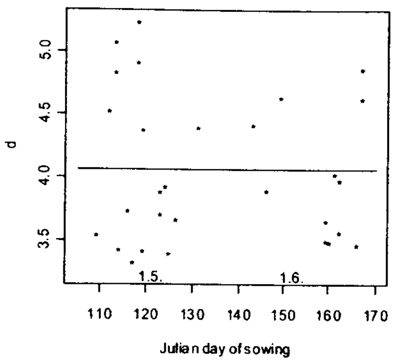

Figure 5. The estimated parameter d as a function of the time of sowing. The horizontal line indicates the average

Fig. 1 shows that the date of growth cessation is rather constant, and the duration of growth since sowing varied much more. Thus the dependency between the time of growth cessation, t1+S, and the sowing time, S, was studied more closely. Fig. 6 shows that there is a slight linear dependency. The obtained regression equation was (RMSE=8.0, R^2=0.16):

$$t_l + S = 211.4 + 0.182\ S \qquad (4)$$
$$(9.8)\ (0.072)$$

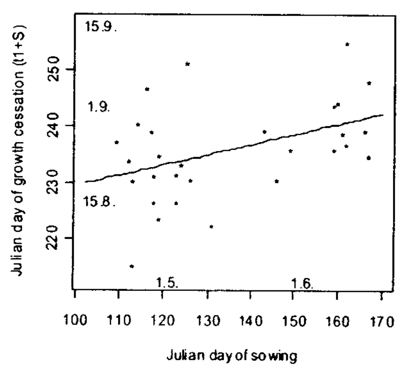

Figure 6. The estimated time of growth cessation, t1+S, as a function of the time of sowing, and the estimated regression line (Eq. 4)

Fig. 7 shows predicted height curves for different sowing times.

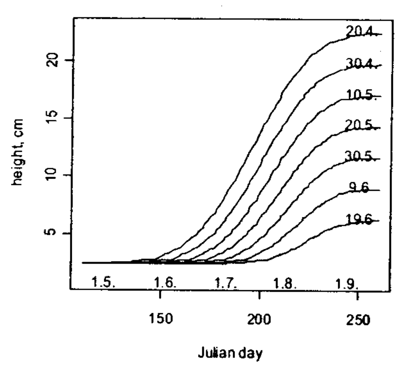

Figure 7. The predicted height curves for different sowing dates

After studying the dependency of parameters on the sowing day, it was then studied if other measured batch variables (total amount of fertilizers, amount of fertilizers per week, total amount of nitrogen, amount of nitrogen per week, average WC, average EC, average temperature) can explain the height growth. If these variables were used alone, some significant relations were found. But if sowing time was in the model, these additional explanatory variables were not significant. Because the effect of growing density and container size were confounded with the effect of the sowing time (A- and B-stocks) they could not be used for studying the dependency.

It was then studied how the cessation of growth is related to the temperature sum and the night length. According to Heide (1974) and Koski and Sievänen (1985) temperature sum at growth cessation is linearly related to the night length. The estimated time of growth cessation is x1+S. It was then computed what is the night length using the sun elevation formula given e.g. by Spitters et al. (1986). The temperature sum (threshold 5°C) was interpolated from the weekly temperature averages.

No clear relation between the termination of height growth and combined effect of photoperiod and temperature sum was found (Fig. 8). There is, however, explanation for the three outlying points indicated by the lot number. The height measurements of lots 5 and 14 were stopped before the height growth started to saturate properly, and thus the time of growth cessation was unreliably estimated. For lot 4 the observed height growth saturated but for so short time that time growth cessation was clearly overestimated. Ignoring the outliers a weak relation can be seen. That the relation is weak is compatible with the above result that the relation between the time of growth cessation and the sowing time was also weak.

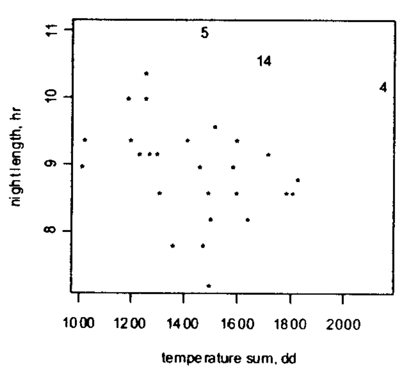

Figure 8. Night length and temperature sum at the height growth cessation. Three outlying batches indicated by the batch numbers

Discussion and conclusions

Sowing time was the best variable to predict the final height of one-year-old Norway spruce seedling crops. The other variables available (temperature sum, EC and WC of growth medium, the amount of fertilizers as nitrogen applied to seedlings) did not increase statistically the explanation of growth model. This can likely be explained by strong correlation between growing time and temperature sum. The EC and WC of peat medium were tried to be kept within optimum levels during the growing season to ensure the sufficient supply of water and nutrients. Therefore they possibly had not marked effect on the height growth of seedling batches.

Uniform speed of germination is emphasized as the most important consideration of sizing (Barnett 1989). In loblolly pine, time of emergence had a strong effect on seedling size which was assumed to be due to the competition which occurs between seedlings within a stand (Boyer and South 1988). However, our operational data did not seem to support that claim. Correlation between germling height and final height was fairly low. The reason could be separate cavities which may lead larger differences in edaphic conditions, water content and nutrient status, among cavities during the season. These differences may decrease the growth of initially well-grown germling and initial size differences may be mixed. The low correlation may partly be explained also by fairly high uniformity of seedling batches.

According to Koski and Sievänen (1985) and Partanen (2004) temperature sum at growth cessation of first year Norway spruce seedlings is linearly related to the night length. In this study the trend was similar but correlation was much weaker (Fig. 8) i.e. this data do not support the idea that the termination of height growth could be predicted accurately on the basis of photoperiod and temperature sum in operational seedling production. Contrary to our data where seedling batches originated from different seed lots although from the same region in the studies of Koski and Sievänen (1985) and Partanen (2004) the relationship was investigated by individual seed lots and similar growing conditions. Also variation in other environmental factors such as timing of fertilization, irrigation and solar irradiance during ten years' time may cause variation in growth cessation (Partanen 2004). In our study some of those factors even were monitored but they did not explain the timing of growth cessation in our static model.

According to 10 years' data of commercially grown seedling batches of a nursery showed that, the best indicator for the final height was the sowing date. Although the measured variables especially average weekly nitrogen amount given correlated with the final height of seedlings, these variables did not give any additional explanation to sowing date.

Modeling of height elongation data of a nursery from longer time period provides a useful tool for crop scheduling when determining sowing date for target size of seedling batches to be shipped on certain dates. In order to be able to schedule, all the crops produced in a nursery also second-year shoot elongation should be modeled.

Acknowledgements

The authors would like to thank Sirpa Kolehmaineh and Jussi Nuutinen from Suonenjoki Research Nursery for preparing and providing the data.

References

Barnett, J.P. 1989. Seed, cultural practices, and seedling uniformity. In: Mason,WL, Deans JL, Thompson S (eds): Producing Uniform Conifer Planting Stock. *Forestry Supplement* 62: 95-105.

Bigras, F., Gonzalez, A., D'Aoust, A.A.L. and Hébert, C. 1996. Frost hardiness, bud phenology and growth of containerized Picea mariana seedlings grown at three nitrogen levels and three temperature regimes. *New Forests* 12: 243-259.

Boyer, J.N. and South, D.B. 1988. Date of sowing and emergence timing affect growth and development of loblolly pine seedlings. *New Forests* 2(4): 231-246.

Hansen, J.M. 1992 Effects of nutritional factors on frost hardening in Larix leptolepis (Sieb & Zucc.) Gord. *Scandinavian Journal of Forest Research* 7(2): 183-192

Heide, O.M. 1974. Growth and dormancy in Norway spruce ecotypes (*Picea abies*). I. Interaction of photoperiod and temperature. *Physiologia Plantarum* 30: 1-12.

Koski, V. and Sievänen, R. 1985. Timing of growth cessation in relation to the variations in the growing season. In: Tigerstedt, P.M.A., Puttonen, P. and Koski, V. (eds.). Crop Physiology of Forest Trees. Proceedings of an International Conference on Managing Forest Trees as Cultivated Plants held in Finland, July 23-28, 1984, p. 167-191.

Landis, T.D., Tinus, R.W., McDonald, S.E. and Barnett, J.P. 1995. The container tree nursery manual. Vol. 1. Nursery planning, development, and management. Agric. Handbk. 674. Washington, DC: U.S. Department of Agriculture, Forest service, 188 p.

Landis, T.D., Tinus, R.W. and Barnett, J.P. 1998. The container tree nursery manual. Vol. 6. Seedling propagation. Agric. Handbk. 674. Washington, DC: U.S. Department of Agriculture, Forest service. 166 p.

Luoranen, J., Rikala, R., Konttinen, K. and Smolander, H. 2006. Summer planting of Picea abies container-grown seedlings: Effects of planting date on survival, height growth and root egress. *Forest Ecology and Management* 237(1-3): 534-544.

Macey, D. and Arnott, J. 1986 The effect of moderate moisture and nutrient stress on bud formation and growth of container-grown white spruce seedlings. *Canadian Journal of Forest Research* 16: 949-954.

Mohammed, G.H. 1997. The status and future of stock quality testing. *New Forests* 13: 491-514.

Partanen, J. 2004. Dependence of photoperiodic response of growth cessation on the stage of development in Picea abies and Betula pendula seedlings. *Forest Ecology and Management*, 188(1-3): 137-148.

Rikala, R. and Heiskanen, J. 1997. Relationship between electrical conductivity and water content of peat growth medium. Suo 48(2): 43-49.

Ratkowsky, D.A. 1990. Handbook of nonlinear regression models. Marcel Dekker. 241 p.

Spitters, C.J.T., Toussaint, H.A.J.M. and Goudriaan, J. 1986. Separating the diffuse and direct component of global radiation and its implication for modeling canopy photosynthesis. Part I. Components of incoming radiation. *Agricultural and Forest Meteorology* 38: 217-229.

Tan, W. 2007. Impacts of nursery cultural treatments on stress tolerance in 1 + 0 container white spruce (Picea glauca [Moench] Voss) seedlings for summer-planting. *New Forests* 33(1): 93-107.

Driessche, R. van den. 1980. Effects of nitrogen and phosphorus fertilization on Douglas-fir nursery growth and survival after outplanting. *Canadian Journal of Forest Research* 10: 65-70.

Received 14 April 200
Accepted 15 March 2010

ПРОГНОЗИРОВАНИЕ РОСТА В ВЫСОТУ ОДНОЛЕТНИХ ГОРШЕЧНЫХ СЕЯНЦЕВ ЕЛИ ОБЫКНОВЕННОЙ В ПИТОМНИКЕ

Р. Рикала и Й. Лаппи

Резюме

В большинстве питомников проводятся наблюдения и документируются сведения об окружающих условиях и различиях в росте выращиваемых сеянцев. Использование этих регулярно собираемых данных для прогнозирования закладки посадочного материала и роста сеянцев не изучалось. С целью прогнозирования роста в высоту выращиваемых в горшечках партий однолетних сеянцев ели обыкновенной мы использовали регулярные данные за 10 лет (информация о показателях роста сеянцев, дневная средняя температура и световой период, еженедельный мониторинг электропроводимости и содержания воды в питательной среде). Наши данные не являются основанием для утверждения того, что в ходе выращивания сеянцев рост в высоту может быть с точностью прогнозирован на основании светового периода и суммарной температуры. Наилучшим индикатором конечной высоты являлась дата посева. Хотя измеряемые величины, в частности среднее недельное внесенного количество азота, были коррелянтны с конечной высотой сеянцев, эти показатели не явились каким-либо дополнительным объяснением для влияния даты посева. Среди партий сеянцев высота всходов (высота сеянца в возрасте 5-6 недель) практически не определило конечной высоты сеянцев.

Ключевые слова: удобрение; ритм роста; сигмоидальная функция; световой период; дата посева; суммарная температура