UNIVERSITY OF IDAHO
COLLEGE OF FORESTRY-WILDLIFE
AND RANGE SCIENCES

EFFECTS OF LIGHT INTENSITY ON SURVIVAL AND GROWTH OF GRAND FIR SEEDLINGS

by

C. M. Norman, H. Loewenstein and F. H. Pitkin

Forest, Wildlife and Range
Experiment Station
Moscow, Idaho

Station Paper No. 17

November, 1974

EFFECTS OF LIGHT INTENSITY ON SURVIVAL AND GROWTH OF GRAND FIR SEEDLINGS[1]

by

C. M. Norman, H. Loewenstein and F. H. Pitkin[2]

INTRODUCTION

Grand fir (*Abies grandis* (Dougl.) Lindl.) was considered economically unimportant in America until the 1950's. Since then, decreased emphasis on management of western white pine (*Pinus monticola* (Dougl.)) because of blister rust has focused attention on the favorable attributes of grand fir.

Grand fir has fast growth, a straight uniform bole, and high wood quality for both pulp and lumber. Additionally, grand fir makes a superior Christmas tree. In the western white pine region of the Inland Empire, grand fir is second only to white pine as a high yielding species. In the overstory grand fir growth is nearly equal to the more intolerant white pine and Douglas fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) with which it is commonly associated. As an understory tree, grand fir usually outgrows the more tolerant western hemlock (*Tsuga heterophylla* (Ref.) Sarg.) and western red cedar (*Thuja plicata* Donn) (Foiles, 1959).

Grand fir often survives poorly when transplanted to the field from nursery beds, but natural regeneration usually produces more than adequate seedling survival and stocking. Because grand fir is shade tolerant, an important determinant of early development on planting sites may be the degree of light intensity to which seedlings are subjected.

The objective of this study was to evaluate the effect of several levels of shade on planted grand fir seedlings. Both a greenhouse and a field experiment were involved in the investigation.

PROCEDURES

Greenhouse Experiment

Three-year-old grand fir seedlings were planted in wax coated fiberboard tubes (one seedling per tube) twenty-four inches deep and four inches in diameter. These tubes were lined with poly-

---

[1] This project was partially supported with funds provided by the McIntire-Stennis Act.

[2] Former graduate assistant and professors of forestry, respectively.

ethylene bags, the bottoms of which were perforated to permit drainage. The potting medium consisted of a 1:1:1 mixture of coarse sand, peat moss and silt loam soil. Watering schedules were arranged to provide adequate moisture levels at all times, regardless of shade treatment. Greenhouse temperature was maintained at 78°F.

In this experiment shade was provided by plastic screening (Shadescreen) of varying mesh size suspended above the greenhouse bench. Treatment ranged from full light intensity (no shading material) to 90% shade; each situation involving 20 seedlings. Natural daylight was supplemented by fluorescent Gro-lux light bulbs, controlled by an electric timer. Day length was held at twelve hours for two months, then extended to sixteen hours for the rest of the experiment period (approximately four more months). Actual light intensity under each treatment was measured in foot candles with a Spectra Candella X-100 light meter. Light quality or intensity of each wave length from 380 mu (millimicrons) to 750 mu was measured under each treatment with an Isco Spectroradiometer (model SR).

Each month photosynthetic and respiratory activity of two seedlings from each treatment was determined in a closed system utilizing a Beckman model 1R-215A infra-red analyzer. Results were calculated as (1) ppm CO_2 absorbed and released per plant per ten minute period, and (2) ppm CO_2 absorbed and released per milligram of tissue per minute.

After photosynthesis and respiration rates were recorded, the seedlings were removed from the potting medium. Length of new shoot growth, new root length, and number of new roots were determined. The seedlings were then oven-dried at 70° centigrade for twenty-four hours, and weights of new topwood, new roots, and new needle tissue were recorded. Treatment effect on survival and percent of seedlings breaking bud was also ascertained.

Field Experiment

The site of this experiment was a 5 degree east-facing slope approximately five miles west of Potlatch, Idaho. The area supports a mixture of ponderosa pine (*Pinus ponderosa* Laws), Douglas fir, and grand fir with an understory of ninebark (*Physocarpus malvaceus*), snowberry (*Symphorocarpus albus*), and ocean spray (*Holidiscus discolor*). Twelve plots, each twenty-four feet long and eight feet wide were marked out in two rows of six plots each. Three-year-old grand fir (bare root stock) of a local provenance were planted in mid-April.

Treatment consisted of (1) full natural light intensity, (2) 47% shade, (3) 73% shade. The shading represented different canopy densities. Experimental design was completely random; each treatment being replicated four times with twenty four seedlings per replicate. Shade screen on light wooden framework was installed the week after planting.

Soil moisture was monitored at weekly intervals by means of Bouyoucos gypsum blocks. One block was placed at eight and another at sixteen inches depth within two randomly selected plots of each treatment. Soil thermometers were installed on these same plots for soil temperature measurements. Relative humidity and air temperature were monitored in the open by a hygro-thermograph. Precipitation was measured weekly by a rain gauge. Light intensity was measured on a sunny day each week during the growing season with a Candella Spectra X-100 meter. Light quality from 380 mu to 750 mu was measured under each treatment with an Isco Spectroradiometer (model SR) at different times throughout the day.

Survival and bud break data were collected throughout the experimental period. Photosynthesis and respiration rates of two randomly selected seedlings in each plot were determined each week for the latter two months of the growing season with the same portable closed atmosphere gas analysis system used in the greenhouse. At the end of the growing season, the two seedlings in each plot which had been involved in photosynthesis and respiration measurements were removed from the soil and subjected to a laboratory analysis similar to that described for seedlings in the greenhouse experiment.

RESULTS AND DISCUSSION

Greenhouse Experiment

Light intensity in the greenhouse averaged only 1600 foot candles for the no shade treatment even with the supplemental lighting used. The relatively low light intensity in the greenhouse as compared to the open sky resulted from white-wash treatment of the glass for temperature control. Meter reading indicated that the actual reductions in light intensity provided by the various shadescreen treatments approximated those to be expected from the manufacturer's specifications.

Shading did not affect light quality. As light intensity was decreased the spectra from 380 mu to 750 mu decreased proportionally and uniformly, with no change in dominant wavelengths. Red light at 600 mu exhibited the highest energy level from 0% shade to 92% shade. Robertson (1966) found this relationship to hold at various north and south latitudes.

Soil moisture and air temperature were maintained at or near optimum, not varying with the degree of shade as could be expected under field conditions.

Light intensity had significant direct and indirect effects on grand fir seedling survival and development, computer analysis of the data revealing many high r^2 values. r^2 is defined as the coefficient of determination or percent of total variation of one variable due to a corresponding variable.

Survival was very good under conditions of full light through 80% shade, ranging between 80% and 100%. Ninety-two percent shade however, resulted in only 65% survival. Correlation between light intensity and survival in the greenhouse was low with an r^2 of .38. Lack of a greater effect can probably be related to the fact that little moisture stress developed in the seedlings, even at full light intensity under the conditions of soil moisture, temperature and air movements maintained in the greenhouse.

The percent bud burst under the different shadings was similar to percent survival. Bud burst and survival are fairly well correlated as indicated by an r^2 value of .72. This was at least partly due to criteria pre-established for estimating survival which required a seedling to break bud and produce new growth during the first growing season after planting. The effect of light intensity on bud burst was not great (r^2 of .31). Veen and Meijer (1959) show day length, rather than light intensity, to be the greatest factor influencing bud burst.

As data concerning photosynthesis and respiration showed similar trends whether expressed on a per milligram needle tissue or a per plant basis, only the latter figures are given here (Table 1). After six months of treatment, seventy-five percent of the total variation in photosynthesis rate was due to light intensity; the higher the light intensity the greater the photosynthetic rate under shaded conditions. Under full light intensity some reduction

Table 1. Photosynthetic and respiration rates of seedlings grown under different degrees of shade in the greenhouse for six months.

Shade Treatment	ppm CO_2 Utilized/ Plant/10 minutes	ppm CO_2 Evolved/ Plant/10 Minutes
0%	17.5	8.0
30%	24.0	8.0
47%	11.0	6.0
55%	9.5	3.0
63%	7.5	3.5
73%	5.5	3.5
80%	3.5	2.5
92%	2.0	1.0

of photosynthesis occurred, but this was not statistically significant. The high r^2 value between light intensity and photosynthesis can be attributed to the favorable environmental conditions of low internal moisture stress which resulted from a low vapor pressure deficit in the greenhouse (Hodge and Scott, 1968).

Photosynthesis was very closely related to the dry weight of new topwood produced ($r^2 = .92$), and dry weight of new needles produced ($r^2 = .87$). The dry weight of these components steadily decreased from 30% shade to the 92% shade treatments (Table 2). Respiration rate was correlated with photosynthesis ($r^2 = .82$). With higher daily photosynthetic activity, the greater the daily and nightly rate of respiration. An indirect relationship of light intensity to respiration ($r^2 = .86$) was apparent.

Table 2. Production of new tissue (dry weight basis) as determined after seedlings grew under different shade treatments in the greenhouse for six months.

Shade Treatment	New Roots (Gms)	New Needles (Gms)	New Topwood (Gms)
0%	2.55	1.60	.40
30%	6.10	1.60	.56
47%	1.03	1.00	.36
55%	.35	.63	.25
63%	.32	.62	.21
73%	.33	.40	.12
80%	.15	.27	.09
92%	.02	.09	.02

The number of new roots produced by each seedling was quite dependent upon light intensity ($r^2 = .67$). This is probably an indirect correlation, being related to the strong effect of light intensity on photosynthesis. Seedlings grown under higher light intensities produced more growth, hence had a higher nutritional demand. New roots were probably produced in order to satisfy this demand from the relatively infertile potting mixture. The number of new roots produced was significantly greater for 0%, 30%, and 47% shade treatments.

Shade treatments did not significantly influence height growth except at the 92% shade level. This particular treatment resulted in significantly reduced shoot elongation.

Field Experiment

Average maximum light intensities were 8,000 foot candles at 0% shade, with 4,000 f.c. at 47% shade and 1,900 f.c. at 73% shade. As found in the greenhouse experiment, the artificial shade did not change the quality of light penetrating the screen, but only reduced the intensities of the spectral energy proportionally. The highest level of energy in the open and under the shade screen again was red light-energy found at a wavelength of 600 mu. The next highest energy levels were in the blue green at 500 mu and blue light at 450 mu. The red and blue energy levels are most important in photosynthesis and chlorophyll synthesis (Robertson, 1966).

Soil moisture conditions were quite good under all treatments until the end of July. The percent available moisture became lowest under the no shade treatment with only 7% available at the eight inch depth during mid-August. At the sixteen inch depth on these plots, available soil moisture dropped to 10%. This percentage is above the 7% lethal limit for grand fir as indicated by Pharis (1966) for heavier textured soils. By the time the available moisture at the eight inch depth had dropped to 7%, many seedling roots had extended beyond the eight inch depth, into zones where there was still available soil moisture. The available soil moisture under 47% and 73% shade only dropped to the 10% level at the eight inch depth during August.

Shading reduced the drying rate of the upper eight inches of soil by modifying the surface soil temperature. As a result soil under no shade dried out faster than soil under 47% and 73% shade during midsummer. However, by the end of the growing season, the soil under 0% shade had a more consistent supply of available moisture than did the other two treatments. Because of interception by the screens on shaded plots, more of the September precipitation infiltrated under 0% shade. In contrast to the situation earlier the lower soil temperatures prevailing at this time prevented much evaporation from these open plots.

Maximum air temperature and lowest percent relative humidity were reached during July and August, promoting a reduction in available soil moisture. These same high temperatures and low relative humidity levels cause higher vapor pressure deficits between the inside and outside of the needles, creating internal moisture stress (Hodges and Scott, 1968).

Light intensity and survival were negatively correlated, with an r^2 value of .74. Survival averaged 19% for 0% shade, 89% for 47% shade, and 79% for 73% shade. This high negative r^2 of .74 can be best explained by the effect of light intensity on early spring temperatures and mid-summer available soil moisture as outlined by Kozlowski (1963). Fairbairn and Neustein (1970) found the highest survival on one-year-old grand fir seedlings occurred under 50% shade, a result in agreement with the present experiment. Survival did not vary much between treatments until internal moisture stress in seedlings began to develop under 0%

shade in early August. This increased stress resulted from a combination of high soil and atmospheric temperatures, and a drop in the available soil moisture. Over 75% of the total mortality for 0% shade occurred during this short mid-summer period. Parker (1951) found mortality to be very dependent upon high internal moisture stress. Development of this stress relates more to the rate of water loss than the actual amount of water lost. Grand fir is fairly insensitive to this stress, reacting slowly to its amplification (Boyd, 1969), so large quantities of water are lost from the needle tissue before stomatal closure begins. Survival was much greater under 47% and 73% shade because of more favorable conditions created by the reduced light intensity. Soil temperature was fairly sensitive to light intensity (r^2 value of .53). The reduced soil temperature under the two levels of shading promoted survival.

Again, as in the greenhouse experiment, correlation between light intensity and bud burst was not great.

Because of mechanical problems with instrumentation, photosynthesis and respiration rates were not measured until high moisture stress had developed. Data concerning photosynthesis and respiration showed similar trends whether expressed on a per milligram needle tissue or plant basis; an example of the information obtained (plant basis) is shown in Table 3. In comparing the relationship to light intensity, photosynthesis appears to be reduced at the highest light intensities although the value was not very great. Hodges (1966) found photosynthesis closely correlated with internal moisture stress. As the internal moisture stress increases, mesophyll resistance of the needles to gaseous exchange increases and this causes photosynthesis rates to decrease. Photosynthetic rate under 0% shade was only half the rate for seedlings developed under 47% and 73% shade. This difference indicates that there was less moisture stress under the shade treatments than in the open.

Pharis (1966) found high internal moisture stress promotes higher respiration rates than photosynthesis rates and subsequent reduction in dry weight of tissue. In the present study, respiration rate is double the photosynthesis rate under 0% shade (Table 3),

Table 3. Midsummer photosynthetic and respiration rates of seedlings grown under different degrees of shade in the field.

Shade Treatment	ppm CO_2 Utilized/ Plant/10 minutes	ppm CO_2 Evolved/ Plant/10 Minutes
0%	4.00	8.50
47%	8.00	5.00
73%	7.25	6.25

result in agreement with Pharis (1966). The respiration rate for the 73% shade treatment is comparable with the rate of 0% shade, both treatments producing greater respiration rates than seedlings under 47% shade. The respiration rate for 0% shade-grown seedlings was higher in midsummer than it was for 47% shade-grown seedlings because of higher internal moisture stress under the open conditions. Probably the respiration rate of seedlings under 73% shade was higher than the rate of seedlings under 47% shade because of higher plant moisture stress resulting from inadequate new root growth to meet the moisture demands of the former seedlings.

Dry weight of new topwood was significantly greater in seedlings grown in the open and under 47% shade than under 73% shade (Table 4), although significance was not shown, it appears that seedlings grown under 47% shade produced more new root and needle tissue than the other treatments. Light intensity did not have a high coefficient of determination with either shoot or root elongation, or number of new roots. However, a definite trend did develop. Length of new shoot growth, length of new roots, number of new roots produced were all greatest under 47% shade.

Table 4. Production of new tissue (dry weight basis) as determined after seedlings grew under different shade treatments in the field for one growing season.

Shade Treatment	New Roots (Gms)	New Needles (Gms)	New Topwood (Gms)
0%	.35	.37	.14
47%	.50	.45	.17
73%	.16	.25	.07

COMPARISION OF GREENHOUSE AND FIELD RESULTS

Under equivalent treatments actual light intensity in the greenhouse was much lower than in the field. As mentioned earlier, this was mainly due to the fact that the greenhouse glass was whitewashed to help maintain lower atmospheric temperatures. On the other hand, light quality was found to be very similar in the greenhouse and field experiments. The highest spectral energy level in the field and greenhouse was at 600 mu (red light). The level of blue light energy in the greenhouse was a little lower than in the field. This small difference should not affect photosynthesis or chlorophyll synthesis.

Differences in soil moisture relations were probably responsible for the difference in results between greenhouse and field experiments. In the greenhouse, plants were well watered and regardless of light intensity there was no internal moisture stress to affect either survival or growth. This is why light intensity had such a high positive correlation with photosynthesis ($r^2 = .75$) and respiration ($r^2 = .86$), and a lower positive correlation with survival ($r^2 = .38$). In the field, light intensity had a high negative effect on survival ($r^2 = .74$) and a low negative association with photosynthesis ($r^2 = .22$), and a low positive association ($r^2 = .19$) with respiration. The higher the light intensity in the field, the greater was the effect of (1) soil temperature on reducing available soil moisture and (2) high air temperatures on lowering relative humidity and increasing the vapor pressure deficit between the inside and outside of the needles. Because grand fir stomata do not react rapidly to internal moisture stresses caused by this combination of high vapor pressure deficit and low available soil moisture (Hodges, 1966) large amounts of internal moisture are lost by transpiration. This rapid loss of moisture is very conducive to seedling mortality (Boyd, 1969) (Parker, 1951).

The use of shade as an instrument for reduction of seedling mortality was a very successful practice in the field, but was not much of a factor in the greenhouse where moisture and temperature regimes were not affected by light intensity. This gives further evidence that high light intensity itself does not directly cause the high mortality found in many field plantings of grand fir. The effect, rather, is indirect through the influence of high light intensity on both soil and atmospheric moisture regimes.

SUMMARY AND CONCLUSIONS

The effects of different light intensities on three-year-old grand fir seedling survival and development were investigated in greenhouse and field experiments. During the course of the work, seedling survival, bud burst, photosynthesis and respiration rates, and shoot and root growth were measured. A randomized block experimental design was employed in the greenhouse with twenty seedlings per block. A completely random design was used in the field work, each treatment being replicated four times (24 seedlings per replicate). Eight levels of light intensity, ranging from 0% to 92% shade were involved in the greenhouse phase; three levels, ranging from 0% to 73% shade were utilized in the field. Various densities of a commercial material named "Shade Screen," placed over a wooden framework provided the required shade.

Soil moisture and soil and air temperatures were kept at favorable levels in the greenhouse; in the field these varied with season and degree of shading. Soil moisture levels under the various treatments as well as other environmental factors were monitored in the field during the growing season.

Greenhouse survival was very high under all treatments except under 92% shade where survival dropped to 65%. Light intensity had little effect on greenhouse survival ($r^2 = .38$), because other environmental conditions of soil moisture, soil and air temperatures were maintained near optimum. Under these conditions no internal moisture stresses developed to cause mortality and seedlings could respond to all of the available light. The low survival under 92% shade was due to low bud burst and poor root growth because light intensity was very low (only 45 foot candles).

Field survival and growth were negatively related to light intensity which strongly affected such environmental factors as soil and air temperatures, available soil moisture and relative humidity. Bud burst was very high regardless of treatment. Survival was very low under 0% shade (19%), much higher under 73% shade (79%) and highest under 47% shade (89%).

The low survival under 0% shade resulted from high internal moisture stress in the seedlings. This stress was promoted by low available soil moisture, higher transpiration rates and low relative humidity. A reduction of light intensity to one half that of full sunlight (8,000 down to 4,000 foot candles), reduced the effect of these stress factors and increased survival more than four-fold.

The results of this study indicate good survival can be obtained on plantings of grand fir seedlings if the planting site is somewhat shaded. A shelterwood area would be ideal in this regard. Because survival is promoted by lower internal moisture stress rather than lower light intensity *per se,* survival rates could also be obtained in completely unshaded field planting areas if sprinkler irrigation systems were available.

LITERATURE CITED

1. Boyd, R. J., 1969, Some Case Histories of Natural Regeneration in the Western White Pine Type. U.S. For. Ser. Res. Pap. INT-63.
2. Fairbairn, W. A., and Neustein, S. A., 1970. Study of Response of Certain Conifer Species to Light Intensity. Forestry 43 (1) : 51-71.
3. Foiles, M. W., 1959. Silvics of Grand Fir. U.S. Forest Service Misc. Publ. Intermt. For. Range Exp. Sta. No. 19, pp. 12.
4. Hodges, J. D., 1966. Patterns of Photosynthesis Under Natural Environmental Conditions. Ecology 48: 234-241.
5. Hodges, J. D., and Scott, D. R. M., 1968. Photosynthesis in Seedlings of Six Conifer Species Under Natural Environmental Conditions. Ecology 49: 773-781.

6. Parker, J., 1951. Moisture Retention in Leaves of Conifers of the Northern Rocky Mountains. Bot. Gas. 113: 210-216.
7. Pharis, R. P., 1966. Comparative Drought Resistance of Five Conifers and Foliage Moisture Content as a Viability Index. Ecology 47 (2) : 211-221.
8. Robertson, G. W., 1966. The Light Composition of Solar and Sky Spectra Available to Plants. Ecology 47 (4) : 640-643.
9. Veen, R., and Meijer, G., 1959. Light and Plant Growth. The MacMillen Company—New York, Phillips Technical Library: 162 pp.