Effects of Ethylene on Development and Field Performance of Loblolly Pine Seedlings[1]

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Abstract.--Ethylene, a plant growth regulator, was produced by loblolly pine (Pinus taeda L.) seedlings in cold storage. Production was cyclic, with a peak occurring that seemed associated with seedling dormancy. Higher than naturally occurring levels of ethylene stimulated root growth potential, bud activity, survival, and growth. However, the intermediate concentrations that were measured in the cyclic peaks had an inhibiting effect on seedling development and performance. Further research is needed to assess the economical significance of these cyclic concentrations on survival and growth.

INTRODUCTION

Ethylene has long been recognized as a naturally-occurring plant growth regulator that is implicated in a number of important physiological processes (Abeles 1973, Galston and Davies 1970). In amounts as low as a few hundred parts per billion, ethylene can inhibit root growth and bud development and reduce seedling vigor (Kramer and Kozlowski 1979, Wareing and Phillips 1973). Stimulation of ethylene production results from mechanical injury such as occurs during lifting of seedlings from nursery beds (Yang and Pratt 1978).

Few of the effects of ethylene on tree seedlings are known, although this subject has received considerable attention in recent years. Barnett (1981) reported a 75 percent increase in root growth potential of loblolly pine (Pinus taeda L.) seedlings stored for 6 weeks in the presence of an ethylene absorbent. Terminal growth of Fraser fir (Abies fraseri (Pursh) Poir.) seedlings was reduced by 22 percent by exposure to 17.5 ppm of ethylene for 8 weeks in cold storage (Hinesley and Saltveit 1980). Graham and Linderman (1981) found that lateral root growth of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings was inhibited at ethylene concentrations greater than 150 ppb.

This paper summarizes a series of studies that have evaluated the physiology of ethylene production in loblolly pine seedlings and the effects of ethylene on seedling development and field performance.

METHODOLOGY

The research with loblolly pine by Barnett (1981) was the stimulus for the later series of studies. In this early work with an ethylene absorbent (Purafil ES®)[3] that improved root growth potential and field seedling survival, three replications of seedlings were stored for 3 and 6 weeks in polyethylene bags with and without packets of the absorbent. In response to the positive results from this work, a cooperative effort began with Dr. Jon Johnson of Virginia Polytechnic Institute and State University. In the first of the studies reported by Johnson

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[3]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

(1983), the atmospheres of two cold storage facilities for seedlings were sampled over a 3-month period during the winter of 1981-82 to determine the extent of ethylene accumulation. Depending upon the location of the facility, biweekly or monthly samples using Vacu-Samplers® were replicated 2 or 4 times. Some sampling of ethylene levels in kraft-polyethylene (K-P) seedling storage bags was also done. The samples were analyzed on a Bendix 2500® gas chromatograph. Complete details of the analysis techniques have been reported (Johnson 1983).

Studies to evaluate the dose-response relationship between ethylene and the performance of loblolly pine seedlings were then conducted. Seedlings lifted late in the season (March) were sealed in K-P bags and exposed to one of six treatments: control, 500 ppb, 1,000 ppb, 2,000 ppb, and 4,000 ppb of ethylene. An additional treatment involved placing a packet of Purafil in the bag with the seedlings. Ethylene concentrations were monitored periodically with gas chromatography, and the concentrations were adjusted as required. The seedlings were stored at 4°C for 6 weeks and then were measured for root growth potential and survival (Johnson and Stumpff 1984b) and for bud activity and first-year heights (Johnson and Stumpff 1984a). The methodology for the estimation of stage of bud development was reported by Johnson and Barnett (1984).

In addition to the evaluation of doseresponse relationships, tests were also conducted to determine the effects of lifting date on ethylene production, identify whether ethylene originated in the roots or shoots, and compare the effect of machine versus hand lifting on subsequent ethylene production. Loblolly pine seedlings were lifted monthly from early to late in the season (November to March). Whole seedlings or roots and shoots individually were packaged in K-P bags for 1 week at 3°C. The ethylene concentration within the bags was measured using gas chromatography (Johnson and Stumpff 1985, Stumpff 1984).

RESULTS AND DISCUSSION

Barnett's (1983) data indicated that the presence of an ethylene absorbent greatly increased root growth potential and improved field seedling survival by 6 percentage points, even after three growing seasons (Table 1). No direct measurements of ethylene production were made, but the data suggest that ethylene is produced by loblolly pine seedlings and that it may be, at least partially, responsible for rapid deterioration of seedlings in storage.

Accumulation in cold storage

Johnson (1983) then evaluated the ethylene concentrations in two cold storage facilities and in a limited number of seedling bales and K-P bags. In the storage facility that handled open seedling bales, ethylene concentrations reached

Table 1.--Root growth potential, survival, and heights of loblolly pine seedlings lifted from nursery beds and stored in polyethylene bags with and without Purafil ES[1] media (from Barnett 1983)

Treatment	Application	Stored 3 weeks			Stored 6 weeks		
		RGP[2]	Survival	Height	RGP[2]	Survival	Height
		No. of new roots	%	Ft	No. of new roots	%	Ft
Without Purafil ES	1	163	92	5.4	80	84	4.8
	2	133	76	4.8	90	80	4.3
	3	120	88	4.5	84	84	4.9
Average[3]		139a	85b	4.8 a	85b	83b	4.7a
With Purafil ES media	1	125	92	4.8	158	88	5.2
	2	106	92	4.3	143	88	4.8
	3	159	88	5.2	147	92	4.5
Average[3]		130a	91a	4.8a	149a	89a	4.9a

[1] Purafil ES is the trade name of the ethylene absorbent.
[2] RGP = root growth potential, which is the number of new roots per seedling after 1 month under controlled conditions.
[3] Means within columns followed by the same letter are not significantly different at the 0.05 probability level for RGP and at the 0.10 probability level for field measurements. Survival and heights reported are those measured after 3 years in the field.

physiologically significant levels (2,300 ppb) in late December (fig. 1). The levels dropped rapidly after this peak was reached, which may have been related to chilling hours or seedling dormancy. Gasoline-powered forklifts were used in this facility and may have added to the ethylene in the atmosphere, but this could not explain the sharp peak in the facility that handled seedling bales. At the other facility, ethylene concentrations remained virtually constant at, or slightly above, the control concentration of 200 ppb. This lack of change was attributed to the use of sealed K-P bags for seedling packaging. Gas samples from within seedling bales and K-P bags indicated that loblolly pine seedlings do produce ethylene.

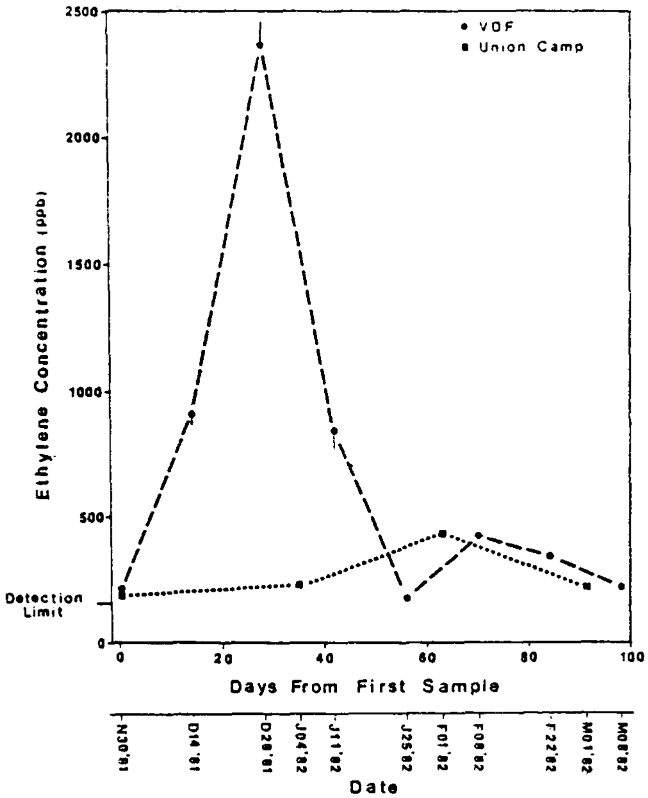

Figure 1.--Ethylene concentration in cold storage facilities of Virginia Division of Forestry and Union Camp during the 1981-82 season. Standard errors are represented by vertical lines where they are larger than the symbols (from Johnson 1983)

Lifting date and method

Evaluations of seedlings lifted monthly from November to March in the following year (1983) and packaged whole or separated into roots or shoots indicated that ethylene production is cyclic, with a maximum concentration occurring in February, perhaps when the chilling hours were met (Johnson and Stumpff 1985). The roots and shoots produced similar quantities of ethylene, about 0.10 ppb/g, except in February when the roots produced about twice as much as the shoots (fig. 2). The significance of this burst of ethylene production is unknown, but it may be associated with the dormancy process. Corroborative data for the involvement of ethylene in bud dormancy comes from a separate study in which bud break was assessed monthly (Johnson and Barnett 1984). In that test, the chilling requirement for bud break was not met until after February 1, 1983. The ethylene peak may correspond with a shift in seedling metabolism from a dormant state of activity in preparation for bud break.

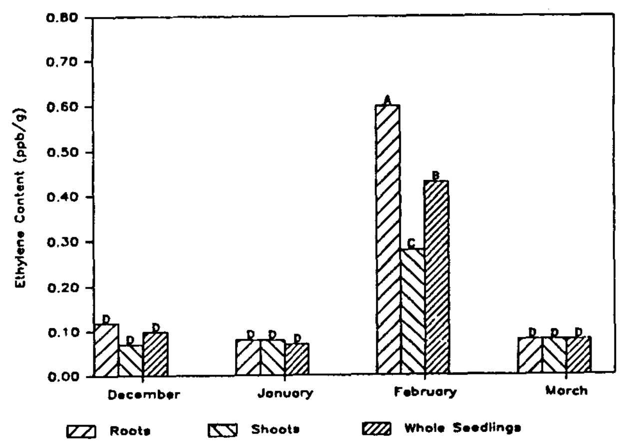

Figure 2.--Ethylene content of K-P bags containing whole seedlings, roots, and shoots of loblolly pine lifted monthly from December to March. Bars with the same letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1985)

Lifting method had a significant effect on ethylene production (Johnson and Stumpff 1985). The amount of ethylene produced remained constant for hand lifting between January and March (fig. 3). As a result of machine lifting, however, ethylene content increased from 38 percent in January to 263 percent in March. Machine lifting not only tended to break roots, but the stems of some were compressed by the belts of the lifting machine. The differences in the amounts of ethylene produced between different lifting dates may reflect the change in dormancy status of the seedlings.

Dosage-rate evaluations

Loblolly seedlings lifted in March were exposed to six ethylene treatments (a control, an ethylene absorbent (Purafil ES), and 500, 1,000, 2,000, and 4,000 ppb of ethylene) and stored for 6 weeks before outplanting. The seedlings were evaluated for root growth potential, field bud activity, survival, and first-year height growth.

Root growth potential, measured both as cumulative length of new roots and total number of new roots, was significantly affected by ethylene fumigation. The 4,000-ppb and 500-ppb treatments resulted in the greatest root growth potential (Johnson and Stumpff 1984b). The Purafil and control treatments were intermediate, while the 1,000-ppb and 2,000-ppb treatments consistently had the lowest root growth potential.

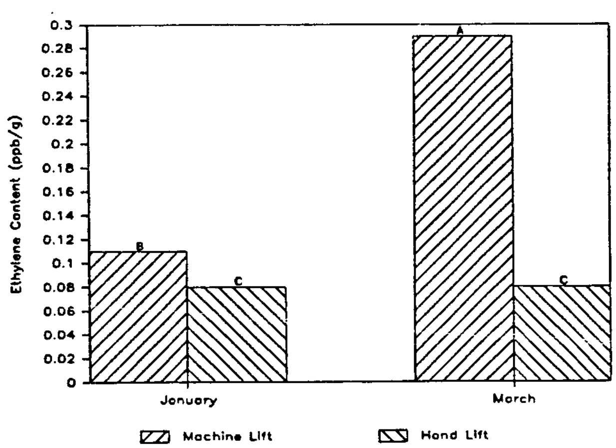

Figure 3.--The effect of lifting method, machine vs. hand, on ethylene content in K-P bags of loblolly pine seedlings lifted in January and March. Bars with the same letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1985).

Bud activity assessed 1 month after outplanting by the method of Johnson and Barnett (1984) was significantly affected by the ethylene treatments (Fig. 4). The 4,000-ppb treatment stimulated bud break, but the responses to the other treatments were essentially the same. Spring bud activity as measured here is probably a reflection of root growth; seedlings that initiate early root growth also break bud sooner (Johnson and Barnett 1984, Johnson and Stumpff 1984b). The 4,000-ppb treatment had a positive effect on both root growth and bud break. Zaerr and Lavender (1980) reported a similar response in early-lifted Douglas-fir seedlings exposed to 5,000 ppb of ethylene during 1 month of storage.

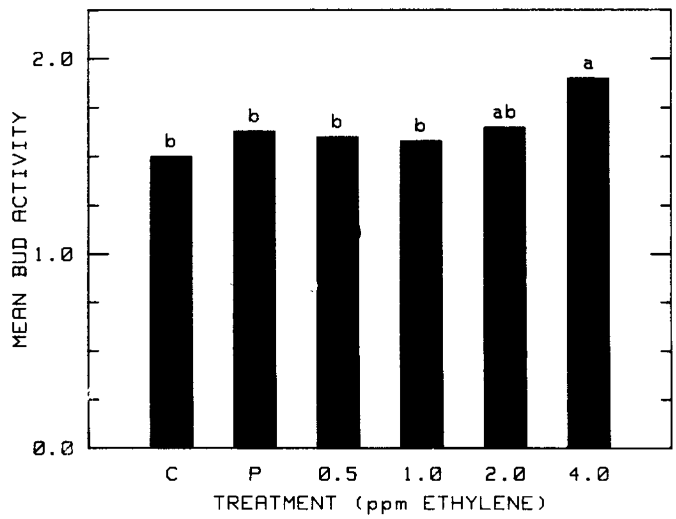

Figure 4.--Mean bud activity 1 month after outplanting of loblolly pine seedlings stored for 6 weeks. Storage treatments were: C - control; P - Purafil; 0.5, 1.0, 2.0, 4.0 - ethylene concentration in parts per million injected and maintained in seedling K-P bags. Bars with the same lower case letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1984b). (Explanation of mean bud activity is given in Johnson and Barnett 1984.)

Survival after 1 year in the field was high, ranging from 94 to 99 percent (Fig. 5). Seedlings fumigated with 4,000 ppb of ethylene averaged 99 percent survival, which was higher than all other treatments except the Purafil treatment. The lowest survival was in the 1,000-ppb treatment, which appears to be in the range of concentration measured in the cold storage facilities. However, survival for all treatments was so great that there were no practical differences.

Seedling heights after 1 year in the field were affected by treatment and, again, the 4,000-ppb treatment promoted the greatest response (Fig. 6). All the other ethylene fumigation treatments resulted in similar heights, while the control and Purafil treatments resulted in lower heights.

The results of these studies illustrate that ethylene is physiologically active in loblolly pine seedlings. The responses may be inhibiting or stimulatory, depending upon the dosage to which particular seedling tissue is exposed.

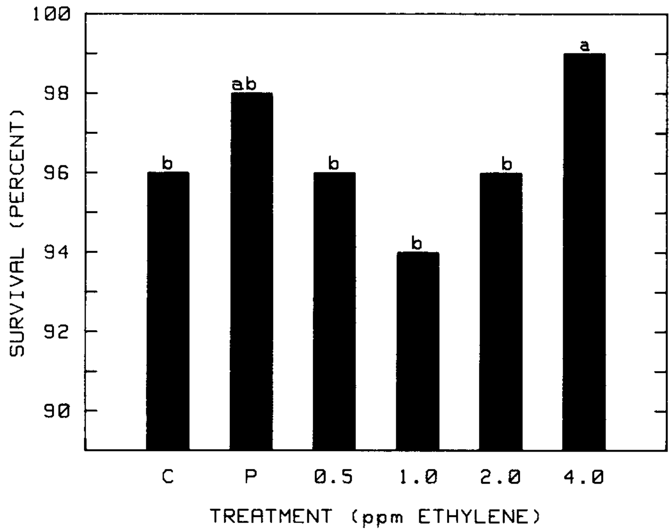

Figure 5.--Survival of loblolly pine seedlings stored 6 weeks after 1 year in the field. (Treatments and statistics are described in figure 4.)

CONCLUSIONS

These results appear to be, at first, conflicting. Ethylene at the 4,000-ppb rate stimulated root growth potential, bud development, survival, and height growth. However, lower concentrations inhibited at least some seedling physiological responses. Abeles (1973) has documented a wide scope of research with other types of plants that demonstrate that ethylene may be inhibiting or stimulating, depending upon concentration.

It is important to note that the 4,000 ppb of ethylene that resulted in positive physiological responses was higher than any level measured under natural conditions in either seedling storage facilities or bags. The 4,000-ppb concentration was also difficult to maintain. Ethylene is a very elusive gas and could not be maintained in sealed K-P bags without repeated fumigation.

Production of ethylene is cyclic, seemingly dependent upon the physiological state of the seedlings. The peaks of production seem closely related to some phase of seedling dormancy. These results must be viewed as an initial attempt to demonstrate the effects of ethylene on seedling survival and growth. Although a reduction in seedling survival due to exposures to ethylene was determined, its overall effect on the performance of loblolly pine seedlings is probably not major. The most practical approach to reducing ethylene concentrations that could affect seedling performance would be to install ethylene-absorbent scrubbers in cold-storage facilities where problems may exist. Further research is needed to assess the economical significance of these cyclic concentrations of ethylene on seedling performance.

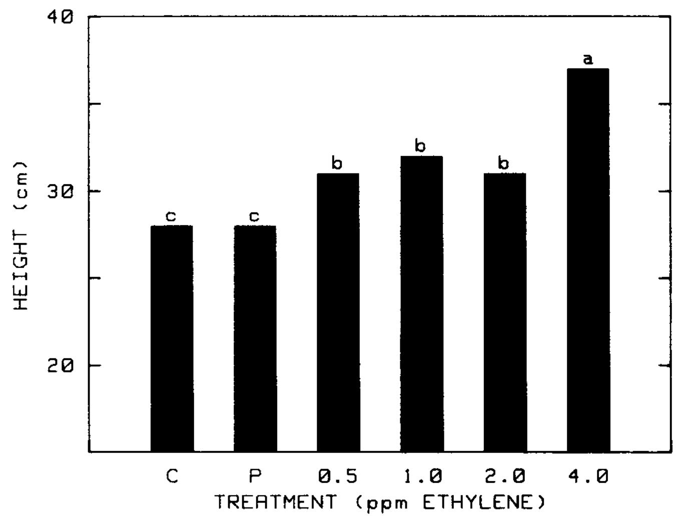

Figure 6.--Heights of loblolly pine seedlings stored 6 weeks after 1 year in the field. (Treatments and statistics are described in figure 4.)

LITERATURE CITED

Abeles, F. B. Ethylene in plant biology. New York, NY: Academic Press; 1973. 302 p.

Barnett, James P. Ethylene absorbent increases storability of loblolly pine seedlings. In: Proceedings, 1980 Southern Nursery Conference; 1980 September 2-4; Lake Barkley, KY; Atlanta, GA: FS Technical Publication SA-TP17. Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1981: 86-88.

Barnett, James P. Ethylene: a problem in seedling storage? Tree Planters' Notes 34(1): 28-29; 1983.

Galston, A. W.; Davies, P. J. Control mechanisms in plant development. New Jersey. Prentice-Hall; 1970. 184 p.

Graham, J. H.; Linderman, R. G.. Effect of ethylene on root growth, ectomycorrhizae formation and Fusarium infection of Douglas-fir. Canadian Journal of Botany 59: 149-155; 1981.

Hinesley, L. E.; Saltveit, M. E. Ethylene adversely affects Fraser fir planting stock in cold storage. Southern Journal of Applied Forestry 4: 188-189; 1980.

Johnson, Jon D. Ethylene accumulation during cold storage of pine seedlings: Is it a problem? In: Proceedings, 1982 Southern Nursery Conferences; 1982 July 12-15; Savannah, GA; 1982 August 9-12; Oklahoma City, OK; Atlanta, GA: FS Technical Publication R8-TP4. Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1983: 224-228.

Johnson, Jon D.; Barnett, James P. Loblolly pine seedling vigor based on bud development. In: Proceedings, 1984 Southern Nursery Conferences; 1984 June 11-14; Alexandria, LA; 1984 July 24-27; Asheville, NC; Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1984: 138-144.

Johnson, Jon D.; Stumpff, Nancy J. Loblolly pine seedling performance is affected by ethylene. In: Proceedings, 1984 Southern Nursery Conferences; 1984 June 11-14; Alexandria, LA; 1984 July 24-27; Asheville, NC; Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1984a: 169-173.

Johnson, Jon D.; Stumpff, Nancy J. The influence of ethylene on root growth capacity and field performance. In: Proceedings, Eighth North American Forest Biology Workshop; 1984 July 30-August 1; Logan, UT. Logan, UT: Utah State University; 1984b: 190.

Johnson, Jon D.; Stumpff, Nancy J. Loblolly pine seedling ethylene production as affected by lifting time and method. In: Proceedings Third Biennial Southern Silvicultural Research Conference; 1984 November 7-8; Atlanta, GA. General Technical Report SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service; 1985: 34-37.

Kramer, P. J.; Kozlowski, T. T. Physiology of woody plants. New York, NY: Academic Press; 1979. 811 p.

Stumpff, Nancy J. Ethylene production by loblolly pine seedlings during cold storage and water stress. Blacksburg, VA: Virginia Polytechnic Institute and State University; 1984. 156 p. Thesis.

Wareing, P. F.; Phillips, I.D.J. The control of growth and differentiation in plants. New York, NY: Pergamon Press; 1973. 303 p.

Yang, S. F.; Pratt, H. K. The physiology of ethylene in wounded plant tissues. In: Kadl, G., ed. Biochemistry of wounded plant tissues. New York, NY: Walter de Grayter and Co.; 1978: 595-622.

Zaerr, J. B.; Lavender, D. P. Analysis of plant growth substances in relation to seedling and plant growth. New Zealand Journal of Forest Science 10: 186-195; 1980.