HARDWOOD COVER CROPS: CAN THEY ENHANCE LOBLOLLY PINE SEEDLING PRODUCTION

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Abstract--It has been extremely difficult to obtain more than two loblolly pine *(Pinus taeda* L.) crops following even effective soil fumigation with methyl bromide in southern forest tree nurseries. The traditional agronomic cover crops such as sorghum and sudex, unless followed by fumigation, do not normally produce satisfactory loblolly pine seedling crops. Various species of hardwoods appear to stimulate the following pine crop even in the absence of fumigation. In the present study, we fumigated immediately before the hardwood and sudex cover crop sequences because no effective herbicide was available to control weeds in the hardwood nursery beds. Heights and root collar diameters (RCD) of loblolly pine seedlings from all cover types were comparable. Stem weights were generally greater for seedlings in the hardwood-pine rotation. Also, the needles were longer and thicker in pine seedlings grown after hardwoods as compared to those followed the sudex cover crop.

Keywords: methyl bromide, *Pinus taeda*, cover crops, hardwoods

INTRODUCTION

Loblolly pine is the most widely planted southern pine and is indispensable to the forest economy of the southern United States. Its importance increased following World War II, and artificial regeneration became the principle method of establishment with the development of the various tree improvement programs throughout the region. Accompanying the increased planting of loblolly pine was a rapid expansion of forest nurseries to provide seedling to meet the planting needs on public, private, and industrial lands. For many years, the demand for pine seedling exceeded the capacities of the established nurseries to produce them, and intervals between cover crops and seedling productions were altered. The compression between cover :rop sequences probably became feasible because of effective fumigation with methyl bromide. Although other soil fumigants are available, maintaining loblolly pine seedling production has relied heavily upon continued use of methyl bromide (Chapman 1992). Before an array of

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fungicides and herbicides began to come on line, this compound appeared to be a panacea for nursery production. It proved to be effective as a preemergent herbicide, as well as a most effective treatment for controlling potentially destructive soil borne organisms (Cordell 1982; James et al. 1993). However, methyl bromide may not be available for use in seedling production after the year 2000 (James et al. 1993).

During many periods of rapid expansion of planting loblolly pine, the numbers of seedlings produced were at least as important as their quality. However, it soon became evident that, essentially, only two acceptable successive pine crops were possible following even effective fumigation (May 1985a). Although most rotation sequences stress buildup of organic matter during the cover crop sequence as being important to maintaining valuable soil properties and fertility relationships (May 1985a; Rose 1993), significantly increasing soil fertility levels have had little effect on undesirable seedlings produced in the third or fourth successive seedling crop. The scientific community has not yet addressed the obvious question of why 3 or more successive southern pine seedling crops are difficult to produce. This is even more unusual when one realizes that different annual crops have been grown for centuries without the benefit of soil fumigation and successive tree rotations have continued for centuries without fumigation. Unfortunately, *methyl bromide's effectiveness masked* the need for researching the biology behind growth decline associated with successive crops of loblolly pine seedlings. Research is needed to determine why successive pine seedling crops, even in absence of potentially destructive soil borne omanism, results in depressed seedling development.

In our early studies on the heritability of first-order lateral roots (FOLR) on loblolly pine at the Institute of Tree Root Biology (ITRB), Athens, Georgia, we would alternate between sweetgum and loblolly pine studies in our experimental nursery beds (Kormanik et al. 1986; Kormanik et al. 1990; Kormanik et al. 1991). Fumigation would follow each sweetgum seedling crop to facilitate introduction of specific ectomycorrhizal fungi into the pine nursery beds. The emphasis of our researches soon focused on the morphology, physiology, and biochemistry of seedling development rather than mycorrhizal relationships. Fumigation to maintain specific ectomycorrhizal fungi was eliminated. After five or six successful sequences at alternating pine and hardwood crops in the same nursery beds without fumigation, the value of hardwoods as a cover crop became evident but was not considered as a practical alternative in commercial nurseries.

Few nurseries were growing many hardwoods in the early 1980s and those that did were using completely different soil fertility regimes for producing pines and hardwoods. These nurseries did not normally precede pine crops with hardwoods because of soil fertility considerations. However, the Georgia Forestry Commission and the U.S. Forest Service ITRB began to develop nursery fertility protocols that maintained the traditional crop rotation but would readily permit alteration of crops between hardwoods and southern pines (Kormanik et al. 1992). Following two pine seedling crops, we found that any number of either ectomycorrhizal or endomycorrhizal hardwood host species developed very well without fumigation. The major problem encountered has been herbaceous weed competition during the hardwood sequence since so few effective herbicides are available to use over them. Thus, fumigation was still recommended before planting the hardwood cover crop as a preemergent herbicide even though presence of potentially destructive soil borne organisms was not evident.

Over a seven year period in our Whitehall Experiment Nursery, Athens, Ga, several 2:1:1 rotations of pine:hardwood:pine proved to be effective without fumigation. We hand weeded during the hardwood sequences and used herbicides to control herbaceous competition during the pine sequence. It was observed in several cases, but essentially ignored, that following the hardwood sequence the pine seedlings were somewhat larger and had darker green foliage than the pine seedlings produced either with or without fumigation in the sudex cover crop sequence. Parallel observations in two of the Georgia Forestry Commission's nurseries indicated a similar situation. Initially no attempt at using hardwoods in a cover crop sequence was considered until we had developed a nursery soil fertility protocol similar to that reported earlier for loblolly pine (Kormanik et al. 1994). After the hardwood protocol was developed, we considered whether hardwood crops could reverse whatever undefined soil effects or microbial problems were induced by successive pine cropping. The short and long term objectives of this research are: (1) to determine response of loblolly pine seedlings following normal fumigation schedules but including various commercially important hardwood species in the cover crop sequence; and (2) to determine the effect of hardwood cover crops on subsequent pine rotations when hardwood cover crops are not preceded by soil fumigation.

METHOD

In 1990, as a normal procedure at the Georgia Forestry Commission's Flint River Nursery, several fields were fumigated and sown with sudex in their cover crop sequence. In the 1991 and 1992 growing seasons, loblolly pine seedlings were produced according to the soil fertility protocol reported by Kormanik et al. (1992). In 1993, one of the fields was fumigated and sown with a sudex cover crop again. This field served as the control. An adjacent field was fumigated and sown with one of 19 hardwood species as the cover crop sequence. The hardwoods were all planted at 65 per m^2 and were grown according to the soil fertility protocol by Kormanik et al. (1994). The field containing the hardwood beds was carefully mapped so that each specie's location could be re-established after the seedlings were lifted. The 19 hardwood species used were: *Ouercus acutissima, O. alba, O. nigra, O. prinus, O. virginiana, O. michauxii, O. rubra, Malus anqustifolia, Diospyros virginiana, Liriodendron tulipifera, Lagerstroemia indica, Liquidambar styraciflua, Plantanus occidentalis, Catalpa bignonioides, Cercis canadensis, Nyssa sylvatica* var *biflora, N. aquatica, Fraxinus pennsylvanica,* and *Carya aqualica.* After lifting the hardwood seedlings, a composite soil sample from each of the 19 hardwood beds and a single composite sample from the field containing the sudex cover crop were collected and sent to the A&L Laboratory (Memphis. Tennessee) for soil analysis.

In March 1994, before sowing in April, both fields had their soil fertility adjusted to the standard baseline used at the Flint River Nursery. Both fields were sown with a precision seed sower to the same mixed loblolly pine seedlot at a planned density of 284 per m2 . Ten randomly located positions were established in beds from which each of the hardwood species had been growing and were monitored at two week intervals for pine seedling height growth. Standardized curves had already been established for the normal sudex cover crop sequences and after mid-July their development was not monitored, except on required intervals.

The nursery protocol requirement is that the seedlings be between 15-20 cm tall by mid-July when the final growing season application of nitrogen is applied. Depending on the actual height in mid-July, additional nitrogen and irrigation can then be applied or held back to obtain final seedling height of 25-35 cm. Unless adjustments are needed, based primarily on environmental conditions, the final nitrogen application is applied in early to mid-September after terminal buds have set and dry weight growth is then being allocated primarily to the root systems (Sung et al. 1993; Sung et al. 1994). With this protocol, seedlings can be lifted for outplanting in early November.

In early November of 1994, seedlings from five of the ten permanent 0.93 m^2 sampling plots were lifted from each of the beds previously grown hardwood species. Root collar diameter (RCD) and height were measured and FOLR were counted. Fresh weights were obtained from two of the five lifted plots to obtain top:root (T/R) ratios. Approximately a total of 6 million seedlings were produced in each of the two fields used in this experiment. Loblolly pine seedlings from the hardwood cover crop beds were the first to be lifted and were all shipped out by mid-December. In early February, only control seedlings from the sudex cover crop beds remained and 5 plots were resampled to follow seedling development during the lifting season. The soils were resampled and both fields were again planted to the same seedlot for their second successive crop during the 1995 growing season for continued study. The current study design precluded statistical analysis of the effects among the 19 hardwood species. No replications among fields were available. This is not an unusual situation for large applied nursery studies such as this one.

RESULTS AND DISCUSSION

The unusually heavy rains during early July of 1994 that caused massive flooding in south Georgia had a significant impact on the entire nursery, including the fields used in this experiment. For extended periods through July and early August, water stood in the allies half way up the raised beds. As is characteristic of any nursery, specific portions of any field may be affected to different degrees by excess water. Thus, while the floods may not have affected the general outcome, they may have affected seedling development in specific portions of the fields. In general, by early August pine seedlings grown after the hardwood cover crop were noticeably greener and had larger needles than those seedlings which followed the sudex cover crop.

Because of their increased vigor, seedlings were lifted beginning the first week of November, 1994. The effects of different cover crops were examined in several fashions.

Seedling Survival

Typically, the Commission allows for a 20% mortality factor during the growing season and increases sowing rate accordingly. The nursery protocol used requires constant monitoring; thus mortality has been less than experienced earlier. This 20% mortality factor is currently being reduced. Overall, in both fields the number of seedlings per m^2 was 299, about 10% more than we planned to have. This should be acceptable even though within some of the sampled plots for any given hardwood cover crop a 15-20% variation from the norm was encountered. The 10% overall increase in seedling survival was attributed to improvements in soil fertility and moisture regimes, and not to cover crop effects. However, the pattern of water logging could easily have affected seedling survival, since the bed space for given species of cover crops often extended 100 meters or more, and some of the species covered four beds. The low survival in some plots was definitely related to long term standing waters.

Seedling Growth

In year to year operations, seedling growth is monitored several times since the normal growth curve for the nursery had been developed with a sudex cover crop sequence for the Flint River Nursery. Mid-July is critically important, for the seedlings should be between 15-20 cm tall in order to reach the 25-35 cm target height at lifting. It is when the seedlings reach the 15-20 cm height that the secondary needles begin to elongate and mature. Stem growth continued for the next two months until terminal bud formation which signals a shift of photosynthates to root growth. This 15-20 cm height can be easily reached in early to mid-June with excessive nitrogen applications. If this occurs, it becomes very difficult to control seedlings growth without root pruning, top clipping, or significant reduction in irrigation (Kormanik et al. 1992; Sung et al. 1994).

Average seedling size with both cover crop sequences were within 1.5-2.0 cm of the desired of the mid-July height (Figure 1). Figure 1 showed the pine seedling growth curves for five of the hardwood cover crop species commonly produced in large numbers in the Commission's nurseries. If the loblolly seedlings reach 15-20 cm much earlier than mid July, it is difficult to slow their height growth down to achieve the specific desirable sizes. However, one can see that seedlings were closer to 15 cm in mid-July and were on the lower side of the desired heights when lifting started. These smaller sizes can readily be attributed to the slow mid-season growth due to early July floodings. We did not want to deviate too much from our normal procedures in the two fields in which this experiment was carried out and thus followed the established fertility protocol in spite of growth reductions the flooding may have caused.

The seedlin g did not shrink between October 17 and November 7 (Figure 1). Seedlings from the same area was used for height monitoring throughout the summer and for final lifting.

Because of flooded conditions, footing was less than ideal and succulent tips were easily damaged. Therefore, seedlings were periodically measured to the tips of the small terminal needles through October. After the seedlings were hardened and lifted, they were measured to the base of the terminal bud, thus causing the apparent reduction in final harvested size.

In Table I, the pertinent growth data for the seedlings from the different cover crops were collected on November 7, 1994 when lifting was initiated. Even on the earliest lifting date, the mean heights and RCD for seedlings for all cover crop types, except for green ash and swamp chestnut oak, were within protocol limits. However, as in mid-July, the seedlings were on the lower end of the desirable limits. The average number of FOLR for seedlings from all cover crops were within acceptable limits (Kormanik et al. 1990; Kormanik et al. 1991). Only two cover crops, swamp chestnut and green ash, produced less top weights than control seedlings from the sudex cover crop sequence. This extra weight resulted from the longer, thicker needles of the seedlings grown after the hardwood crops. The difference among foliage characteristics usually becomes quite evident between the hardwoods and sudex cover crops by mid-August. Although we have not attempted detailed soil investigations at this time, the effect almost appears similar to several short interval applications of a foliar fertilizer. It may well be that it takes several months for the residual hardwood roots to decompose. The more succulent sudex roots may be breaking down before the pine root systems have developed sufficiently to benefit from cover crop root decomposition and resulted release of nutrients into the soil. In this case, hardwood cover crops proved to be noticeably beneficial to loblolly pine seedling development.

It has been reported that T/R ratio of 1:1 or 2:1 are most desirable for loblolly pine (May 1985b). Anything approaching these ratios are attainable only if mechanical top clipping is undertaken with just about any nursery protocol being used in Southern pine seedling nurseries. We have found that top:root ratios of 7:1 and 8:1 are characteristic during the early part of the lifting season and has not affected survival or growth of outplanted seedlings. The biology of loblolly pine seedling seasonal root development readily accounts for these ratios and is apparent in Control 2 (Table I) and has been reported (Sung et al. 1993). In Table I, from early November to mid-February, tops of pine seedlings after the sudex cover crops increased by only about 18% and the root weights increased by over 100%. Thus T/R ratio was reduced from 6:1 to 3:1. This latter ratio is the approximately T/R recently reported for mature loblolly pine (Van Lear and Kapeluck 1995) and is characteristic for 3-9 year old loblolly pine in plantations (Kormanik, unpublished data). Interestingly, seedlings grown at 130 per m^2 at the Flint River Nursery in 1994 with the heavier applications of nitrogen recommended by others for nursery production of loblolly pine had T/R ratios as large or larger than those observed in this study. For example, in November, 1994 root pruned seedlings were 38 cm tall with 5.5 cm RCD and 8:1 T/R ratio. The unpruned ones were 45 cm tall with 6.0 cm RCD and 9:1 T/R ratio when lifted in early November. Thus, while hardwood cover crops appear to benefit the loblolly pine seedling development, it is difficult to say if, or how, this affects T/R ratio, since tops and roots respond as a unit rather than separate entities.

Whether the benefits of hardwood cover crops are due to the heavier fertilization program utilized in their production and/or changes in the soil microbial relationships is currently open to speculation. We don't know whether one large scale hardwood cover crop can be effective without being preceded by soil fumigation. Certainly, the many beneficial effects of using methyl bromide, even in absence of known destructive soil borne organisms, cannot be discounted. However, the price that was paid scientifically for chauvinistic reliance on methyl bromide may turn out to be high since it seriously reduced research in specific areas such as soil born organisms and soil mediated processes in nursery soils. Nevertheless, this research clearly demonstrates that under the proper soil fertility programs, hardwood cover crop rotations may have a significant advantage over the traditional ones .

CONCLUSIONS

In many early trials, hardwood cover crops proved beneficial to succeeding loblolly pine crops. Even with uncharacteristic flooding affecting this study, the beneficial effects of the hardwood cover crop was quite obvious. How a second pine crop develops after a hardwood crop is currently being followed. The question that must be clarified is whether hardwood cover crops, in the absence of known root pathogens, can eliminate the depressive effects of repetitive loblolly pine crops without the benefit of soil fumigation. This is a critical question that must be examined before methyl bromide and other effective soil fumigants are banned from forest nursery practices. Their demise at this time would be a serious blow to economic production in many Forest Tree Nursery programs.

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Figure1. Cumulative height growth of first year loblolly pine seedlings during1994 at the Georgia Forestry Commision Flint River Nursery following different hardwood species used as cover crops in 1993.

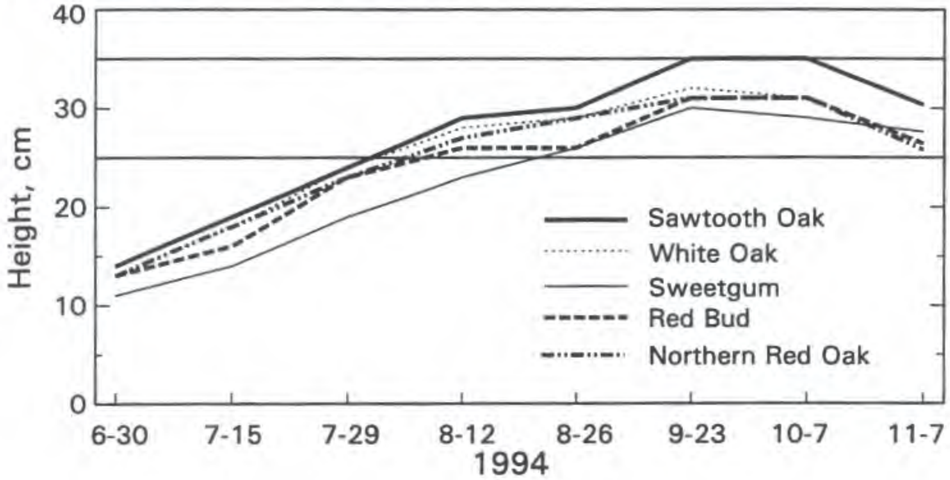

Table I. Loblolly pine 1-0 seedling morphological and growth data following different cover crops. Control cover crop is sudex. Seedlings from all treatments were lifted on November 7, 1994.

Cover crop	FOLR #	Ht cm	RCD mm	Top FW g	Root FW g	T/R Ratio
Sawtooth oak	5	30.3	4.1	11.2	1.5	8 : 1
White oak	4	26.7	4.0	10.0	1.4	7 : 1
Water oak	5	26.6	4.0	8.3	1.1	8 : 1
Chestnut oak	4	26.7	3.8	8.3	1.1	8 : 1
Live oak	5	28.8	4.0	10.7	1.4	8 : 1
Swamp chestnut oak	3	24.3	3.4	5.6	0.9	6 : 1
Nothern red oak	4	25.8	3.6	7.7	1.2	7 : 1
Crabapple	5	26.1	4.0	8.3	1.2	7: 1
Persimmon	5	28.9	4.0	9.4	1.1	8: 1
Yellow poplar	3	28.8	3.7	8.7	1.2	8 : 1
Crepe mrytle	4	27.5	3.7	8.6	1.1	8 : 1
Sweetgum	4	25.9	3.6	8.0	1.3	6: 1
Sycamore	4	25.1	3.7	7.5	1.2	6: 1
Catalpa	4	25.6	3.7	7.6	1.1	7 : 1
Redbud	4	26.4	3.8	8.3	1.2	7: 1
Swamp tupelo	5	28.3	4.2	10.3	1.8	6 : 1
Water tupelo	6	26.8	4.2	8.6	1.7	5 : 1
Green ash	4	22.8	3.4	6.3	1.1	6 : 1
Water hickory	5	26.2	3.8	8.9	1.7	5 : 1
Control 11/7/94	4	25.4	3.7	7.0	1.1	6: 1
Control 2/15/95	6	26.2	4.4	8.3	2.5	3: 1