

IRRIGATING FOREST PLANTATIONS

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Abstract.--Irrigating forest plantations cannot be justified economically on yield increases alone under present market conditions. Other factors such as bringing noncommercial land into high production, insuring a constant wood supply, or providing a means to dispose of wastewater can add to the value of increasing yields and may make irrigation feasible in certain situations.

A major reason for irrigating forests is to increase yields. However, yield increases alone do not offset the added costs of irrigation (Rose et. al. 1981). Other associated benefits of irrigation are the reduced costs for land, harvesting, transportation, and land taxes that result from growing more fiber on less acreage (Mace and Gregersen 1975). These benefits bring irrigation closer to a break-even point. Additional potential benefits of irrigation that have been identified are to provide a means to dispose of wastes, (Hansen et. al. 1980), insurance against drought (Rose and Kallstrom 1976), and a secure source of raw material to a mill that would be costly to shut down (Rose et. al. 1981). But these values are difficult to assess and have not been incorporated into economic analyses of forest irrigation.

Even though forest irrigation has been done experimentally for more than 50 years, I am aware of only one area with a large acreage of irrigated plantations--340,000 acres in West Pakistan (Sheikh 1974). Consequently, the forestry literature contains little discussion of irrigation strategy from a management or economic viewpoint. However, the agricultural literature contains much parallel information. This paper examines some of the reasons behind the decisions for irrigated farming and applies that reasoning to the irrigation of short rotation intensive culture (SRIC) plantations. Benefits and possible negative aspects of irrigation are discussed with illustrations from data collected in irrigated hybrid poplar plantations in northern Wisconsin.

For purposes of illustrating benefits on yield, an idealized view of the relation of tree yield to soil moisture is shown in Figure 1. Although the shape of the yield function over the range of soil moisture is not known, we do know that for a particular species on a specific site no tree growth will occur both at some very dry condition, and at the other extreme of some very wet condition. Somewhere in between these two extremes of soil moisture, tree growth reaches a maximum, the exact optimum soil moisture level varying with tree species. The right hand portion of the function illustrates excessive soil moisture and represents the condition where drainage would increase tree growth. The left hand portion of the function illustrates soil moisture deficiency and represents the condition where irrigation would increase tree growth. It is this drier portion of the soil moisture range that is of interest in this discussion.

Why Irrigate

Tree growth within the humid temperate region varies widely over a range of soil moisture conditions. Under these climatic conditions, irrigating dry sites may possibly produce growth rates similar to those naturally occurring on the very best sites--other factors being the same. Irrigation may be thought of as merely a substitute for insufficient soil moisture storage capacity. Depending upon the existing soil moisture holding capacity, sites may range from being incapable of supporting tree growth without irrigation to showing no additional growth response to irrigation. The value of irrigation for different severities of soil moisture deficit on agricultural soils has been discussed by Greenshields (1955), Tharp and Crickman (1955), and Marr (1967). I have summarized these irrigation benefits

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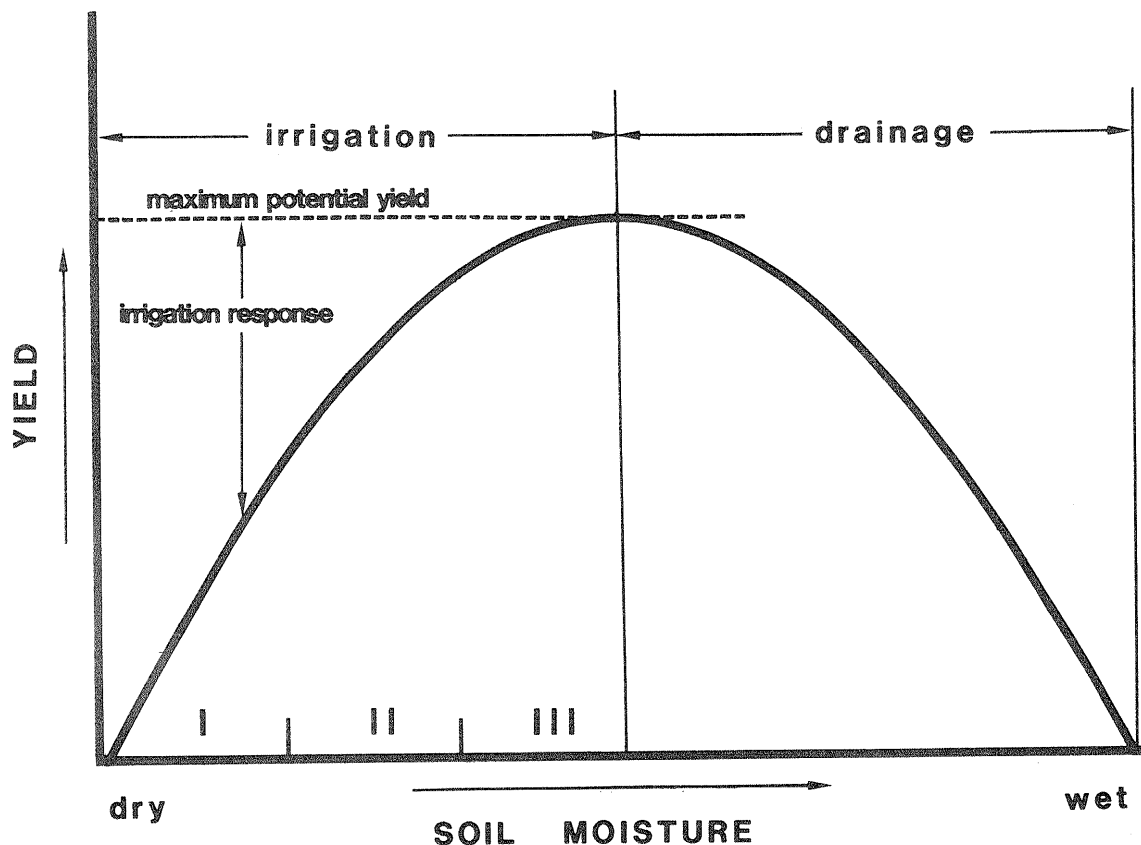


Figure 1.--Relation of tree yield (fiber or energy) to soil moisture. Irrigation (left half of the curve) can increase yield from the existing level, as illustrated by the curved line, up to the maximum potential yield. Drainage of the wet portion of the soil moisture spectrum can produce the same yield responses. Advantages of irrigation are classified into three categories:

Category I: create new commercial forest land.

Category II: increase probability (insurance) of producing a crop.

Category III: increase yield.

by classifying yield response into three arbitrary categories based on the value to a forest manager (fig. 1).

Category 1 represents very droughty soils where either there is no tree growth or the existing trees are noncommercial. Irrigating such land creates new commercial forest land. It is under these conditions that irrigation provides maximum gain in wood production.

Category 2 represents land capable of supporting forest without irrigation. However, chronic soil moisture deficits may substantially depress tree growth and infrequent droughts may result in substantial mortality or a crop failure. Irrigation under these conditions increases the probability of producing a

commercial forest crop.

Category 3 represents land that is nearly certain of having sufficient soil moisture to produce a forest crop. Irrigation would slightly increase yields in most years.

The advantages of irrigation when viewed from this perspective are threefold. Increases in forest yield occur in all three categories, although the magnitude of increase differs greatly from one category to another. However, the important gains are that as sites become drier, irrigation has the added benefits of insuring that a crop will be obtained and creating new commercial forest land. The value of these latter two benefits would obviously differ by geographic area and by individual

wood users within an area.

Irrigation Effects on Yield

A review of more than 80 papers dealing with agronomic and horticultural crops concludes that yields are usually greatest with the wettest soil moisture regimes (Stanhill 1957). A review of forest irrigation indicates that irrigation usually increases tree growth (Hansen 1978). Even small decreases in soil moisture tension will increase the growth of forest trees (Zahner 1968). Irrigation research with hybrid poplars supports these conclusions. Preliminary results based on 3 years of irrigating hybrid poplar planted at 1 x 1 m spacing at Rhinelander, Wisconsin, show that irrigation consistently increased tree growth (fig. 2). In this study plots

were irrigated whenever soil moisture reached the designated treatment level. For example, whenever the soil moisture reached -1.5 bar, the plots assigned that treatment were irrigated to field capacity. Consequently the wettest (-0.3 bar) treatment plots were irrigated 3 to 6 times during the summer whereas the drier (-1.5 bar) treatment plots were only irrigated 0 to 4 times. The "no-irrigation" plots served as a control.

The wettest irrigation treatment of -0.3 bar produced yields 76 and 44 percent greater than the unirrigated controls at the end of the second and third growing seasons, respectively (Table 1). The effect of irrigation on increased yield in weight was the same both years (about 1.5 t/ha/yr).

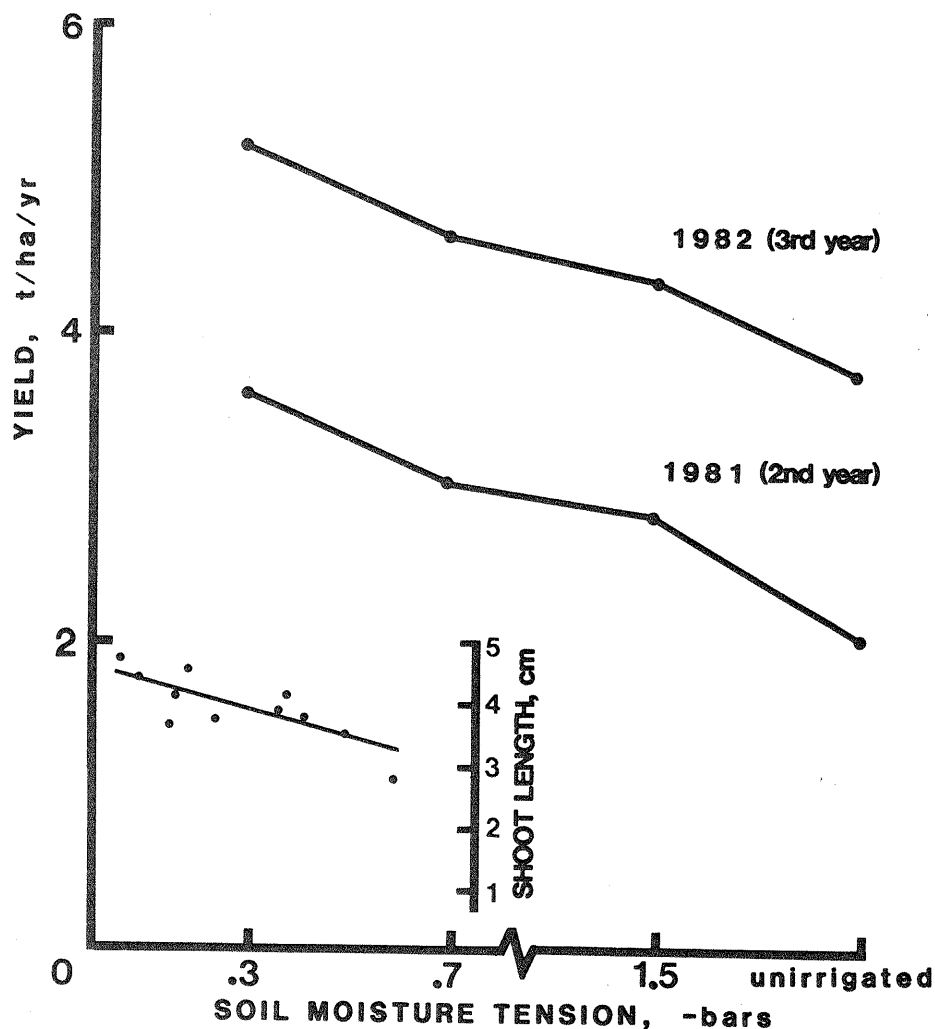


Figure 2.--Effects of soil moisture tension (irrigation) on 10 day shoot length and on 2nd and 3rd year yields.

Table 1.--Effect of irrigation on yield.

Year	Treatment		yield increase	
	-0.3 bar	not irrigated		
		t/ha/yr		%
2	3.5	2.0	1.5	76
3	5.3	3.7	1.6	44

What Soil Moisture Tension is Best?

The same irrigation study showed that tree growth during a 3-year period was satisfactory under all irrigation treatment regimes including no irrigation, but tree growth was greatest with the highest irrigation treatment (fig. 2). Although the highest level of irrigation increased total aboveground yields by 44 to 76 percent, irrigation is not essential for growing trees on that site and so far has not been needed as insurance against infrequent drought. Consequently, this site would probably fall within Category 3 (or possibly 2) (fig. 1).

We investigated the effects of soil moisture tension from -0.6 bars to -0.05 bars on early growth of hybrid *Populus* hardwood cuttings in a growth room (Hansen and Phipps, in press). The soil moisture treatments were obtained by using boxes, each filled with soil at a different soil moisture tension. Unrooted cuttings were then placed in the boxes and we observed their early growth.

The results indicate that bud opening and shoot growth begins sooner as soil moisture tension decreases to at least -0.05 bar (fig. 2). The results of this growth room study together with the results of the field study indicate that the conclusions of Stanhill (1957) and Zahner (1968) also apply to hybrid poplar, i.e., yields are greatest with the wetter soil moisture regimes.

When to Irrigate?

It is sometimes argued that irrigation is most important during plantation establishment, because at this time drought might result in total failure of the plantation (Rose et. al. 1981). In contrast, absence of irrigation in older plantations presumably might only reduce growth but not affect survival, assuming that the plantation is established on a site of at least moderate quality. But is this the case? And how frequently might such conditions occur?

In 1981 we studied growing season soil moisture conditions under a newly established plantation and also under a 2-year-old plantation both with and without irrigation (fig. 3). Soil moisture stress reached higher tensions under the 2-year-old plantation. Irrigation did not produce significant differences in tree height growth in the new plantation but did produce significant biomass differences with the 2-year-old trees.

Rain during July and August of 1981 was well below average:

	July	August
Average precipitation (mm)	3.53	4.27
1981 precipitation (mm)	1.18	0.82

Despite this exceptionally low rainfall, the newly planted unirrigated plots survived and grew satisfactorily. Therefore, it appears that severe mid-to late-summer droughts do not prevent establishment of hybrid poplar plantations in northern Wisconsin.

These plots had good weed control. Soil moisture tensions in weedy plantations would be more severe. Also, drought in May or June might have a negative impact on survival. Both these factors might increase the need for irrigation during plantation establishment. On the other hand, soil moisture in northern Wisconsin is at field capacity in early spring, soil moisture can be conserved by good weed control, and cuttings can be soaked prior to planting to compensate for "dry" (-0.6 bar) soil moisture conditions (Hansen and Phipps, in press). These latter three factors decrease the possibility of encountering severe moisture problems in early spring when establishing plantations.

Although irrigation may in some cases be essential to establish a plantation, it appears that such instances are infrequent in northern Wisconsin.

Negative Effects of Irrigation

It is sometimes argued that irrigation will promote leaf diseases because of increased duration of leaf wetness (Rose et. al. 1981, Schipper 1976, Uriu and Magness 1967). However, the total duration of leaf wetness during a growing season is affected only to a very minor extent by irrigation. Typically, we irrigated on only 1 or 2 days per month whereas it rained on 8 to 15 days per month (table 2). Even in a very dry month rainy days outnumbered irrigation days by 2 to 1

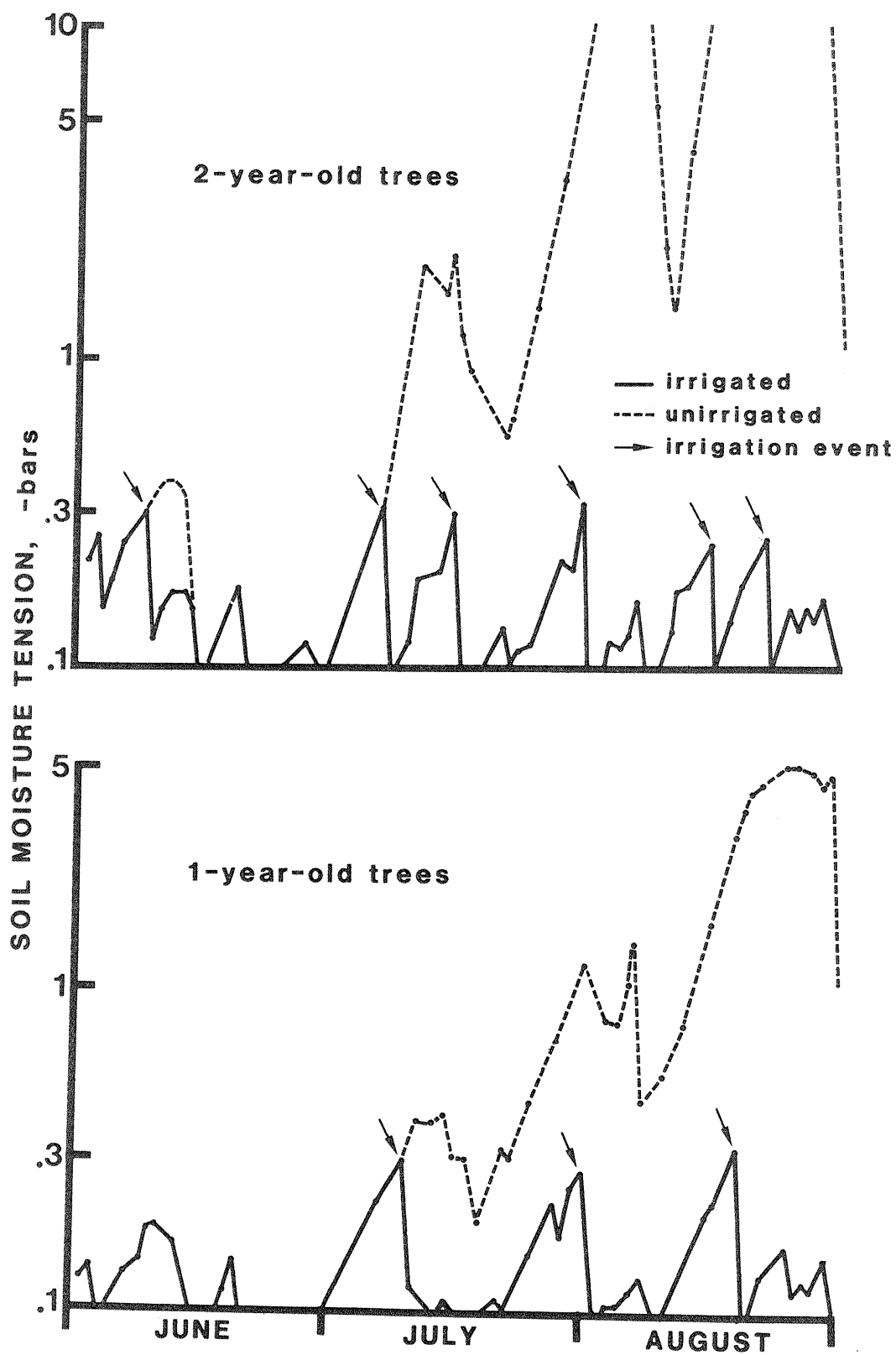


Figure 3.--Soil moisture tension trends under intensively cultured plantations with and without irrigation during the 1st and 2nd growing seasons. Irrigation was done when tensions reached -0.3 bar.

Table 2.--Comparison of the number of days per month with precipitation (P), or irrigation when soil moisture tension reached -0.3 bar (I.₃) or -0.7 bar (I.₇) during the first three growing seasons. Irrigation lasted less than 1 hour for a particular tree; precipitation typically lasted from one to several hours. Frequently it rained several times in 1 day, and occasionally it rained an entire day.

Month	1980			1981			1982		
	P	I. ₃	I. ₇	P	I. ₃	I. ₇	P	I. ₃	I. ₇
-----days-----									
May	5	0	0	7	0	0	12	0	0
Jun	11	1	0	15	1	0	6	2	2
Jul	13	1	0	6	3	1	12	2	1
Aug	14	1	0	8	2	1	8	2	1
Total	43	3	0	36	6	2	38	6	4

when compared to the wettest irrigation regime (see July 1981 when only 1/3 of the normal monthly rain occurred). Even then only one irrigation was applied to the -0.7 bar treatment, which is a common soil moisture tension level in agronomic practice at which to irrigate. A maximum of 6 irrigation days in any one season compares with 36 to 42 rainy days in the same period.

An additional factor is that irrigation of a particular tree lasts less than an hour under our travelling gun system. In contrast, rain may last anywhere from a fraction of an hour to a day. Also, weather conditions associated with rainfall often minimize evaporation so that leaf surfaces remain wet for a long time. In contrast, irrigation is usually done when weather conditions are dry and leaves dry rapidly, thus minimizing duration of leaf wetness. The greatest number of irrigation days occur in dry years. Wet years may need no supplemental irrigation. Therefore, irrigation tends to bring leaf environmental conditions in dry years slightly closer to that experienced naturally in wet years.

Another factor to consider in addition to rain and irrigation is the occurrence of dew. Although we have no direct measurements of dew formation, relative humidity data can be used as an index of the presence of dew. During the June - August growing season, relative humidity reached 100 percent almost every night each of the 3 years and remained at 100 percent for generally 6 to 12 hours. Although relative humidity of 100 percent is not conclusive proof that dew occurred, it is supported by field observations that dew was present almost every night during the summer growing season and normally persisted until mid-morning of each day.

It appears that irrigation is a minor factor in increasing the frequency of leaf wetness during the growing season. It also seems unlikely that the duration of wetness from irrigation will exceed that of either rain or dew. Therefore, irrigation is probably not an important factor in the spread of tree diseases.

Discussion

Analyses conclude that irrigation is not economical for hybrid poplar SRIC plantations yielding 15 t/ha/yr (Rose et. al. 1981). And the yield used in these analyses has been reached only in two of our small research plots (Ek and Dawson 1976). Therefore, this yield could be considered a record. Boyer (1982) shows that average yields for grain crops are only 1/7 that of record yields. Crops such as potatoes and sugar beets with marketable vegetative structures have average yields about 1/3 that of the record yields. Therefore, it seems likely that the average yields of hybrid poplar will be much less than (perhaps half?) the 15 t/ha/yr achieved in our small research plots. Although further research in intensive culture will likely increase yields, it will probably be a long time before the present average yields increase to the levels of the record yields. Therefore, it is unlikely that irrigation will soon become economical when justified on average yields that may be achieved in the foreseeable future.

It does not seem likely that irrigation will be justified based on its need for establishing plantations. Our data show little need for irrigation during the year of plantation establishment, even during an exceptionally dry summer. Also, the establishment period is one of the few times when alternatives to irrigation are available for managing

soil moisture. Good weed control can substitute for irrigation and at a fraction of the cost. For example, post-planting weed control costs from \$3.00 to \$13.00/acre compared with irrigation costs of \$100/acre for annual operation plus \$43.00/acre fixed cost for equipment (Rose et. al. 1981).

Irrigation probably has little impact on the duration of leaf wetness during the growing season. Therefore, it seems likely that irrigation is not an important factor in the spread of tree diseases.

Irrigation has not been able to be economically justified based on its influence on woody biomass yields in the past, and it seems that justification based on further increases in yields will be difficult in the foreseeable future. Consequently, if irrigation is "to pay", it must do so on the basis of other benefits in addition to the documented favorable impact on yields. Additional justification for irrigation must rely to a large extent upon 1) the value of bringing new (previously unproductive) land into the highest levels of production and being able to locate such land near a mill, and 2) the insurance value of greatly reducing risks of growth or mortality losses directly from drought or from secondary attacks by insects and diseases thus assuring a stable fiber supply. Also to be considered is the value of using the land for wastewater disposal via irrigation. These factors must be considered in any determination of whether or not to irrigate, even though their consideration may be highly subjective. Although analyses have shown irrigation of SRIC plantations with a travelling gun system to be uneconomical when based on yields alone, other factors may make irrigation attractive to some large forest land holders.

LITERATURE CITED

- Boyer, J. S. 1982. Plant productivity and environment. *Science* 218:443-448.
- Ek, A. R. and D. H. Dawson. 1976. Actual and projected growth and yields of *Populus* 'Tristis #1' under intensive culture. *Can. J. For. Res.* 6:132-144.
- Greenshields, Elco L. 1955. The expansion of irrigation in the west. In *Water, The yearbook of Agriculture 1955*. U.S. Government Printing Office, Superintendent of Documents. Washington 25, D.C. p. 247-251.
- Hansen, Edward A. 1978. Forest irrigation: a review. In *Proceedings, Soil moisture... site productivity symposium*. Myrtle Beach, South Carolina, November 1-3, 1977. pp. 126-137.
- Hansen, Edward A., David H. Dawson and David N. Tolsted. 1980. Irrigation of intensively cultured plantations with paper mill effluent. *TAPPI* 63(11):139-143.
- Hansen, Edward A. and Howard M. Phipps. Effect of soil moisture tension and presoaking on early growth of hybrid *Populus* hardwood cuttings. *Canadian Journal of Forest Research*. (In press)
- Mace, Arnett C. Jr., and Hans M. Gregersen. 1975. Evaluation of irrigation as an intensive cultural practice for forest crops. *Iowa State Journal of Research*, 49:305-312.
- Marr, Paul D. 1967. The social context of irrigation. In *Irrigation of agricultural lands*. Robert M. Hagan, Howard R. Haise, Talcott W. Edminster and R. C. Dinauer, editors. Number 11 in the series of *Agronomy*, American Society of Agronomy, Publisher, Madison, Wisconsin. pp. 12-22.
- Rose, Dietmar, Karen Ferguson, David C. Lothner and J. Zavitzkowski. 1981. An economic and energy analysis of poplar intensive cultures in the Lake States. U.S. Department of Agriculture Forest Service, Research Paper NC-196, 44 p. U.S. Department of Agriculture Forest Service, Research Paper NC-196, 44 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.
- Rose, Dietmar W., and Robert D. Kallstrom. 1976. Economic feasibility of intensive culture. In *Intensive plantation culture (five years research)*, p. 96-108. U.S. Department of Agriculture, Forest Service, General Technical Report NC-21, U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.
- Schipper, Arthur L. Jr. 1976. Poplar plantation density influences foliage disease. In *Intensive plantation culture (five years research)*, p. 81-84. U.S. Dept. of Agriculture, Forest Service, General Technical Report NC-21, U.S. Dept. of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.
- Sheikh, Mahmood Iqbal. 1974. Optimum water requirement of shisham *Dalbergia Sissoo* - second assessment. *The Pakistan Journal of Forestry* 24(1):1-9.
- Stanhill, G. 1957. The effect of differences in soil-moisture status on plant growth: a review and analysis of soil moisture regime experiments. *Soil Sci.* 84(3):205-214.
- Tharp, Max M. and C. W. Crickman. 1955. Supplemental irrigation in humid regions. In *Water, The yearbook of agriculture 1955*. U.S. Government Printing Office, Superintendent of Documents, Washington 25, D.C. p. 252-258.

- Uriu, K. and J. R. Magness. 1967. Deciduous tree fruit and nuts. In Irrigation of agricultural lands. Robert M. Hagan, Howard R. Haise, Talcott W. Edminster and R. C. Dinauer, editors. Number 11 in the series of Agronomy, American Society of Agronomy, Publisher, Madison, Wisconsin pp. 686-703.
- Zahner, R. 1968. Water deficits and growth of trees. In Water deficits and plant growth II. (T. T. Kozlowski, ed.) Academic Press, New York. pp. 191-254.