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Effect of plantation establishment on soil and soil water in SOUTHWESTERN WISCONSIN

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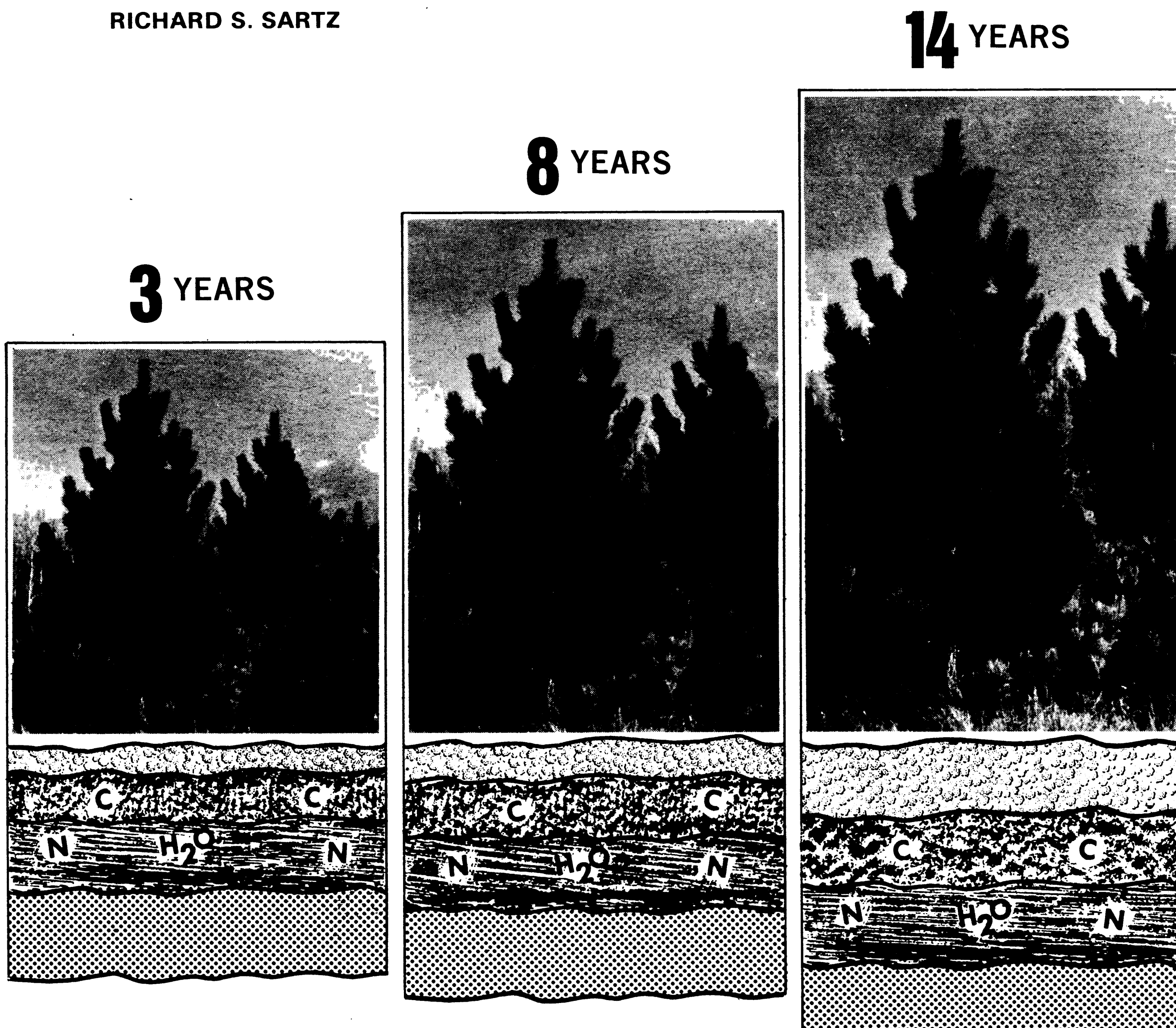

NORTH CENTRAL FOREST EXPERIMENT STATION
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EFFECT OF PLANTATION ESTABLISHMENT ON SOIL AND SOIL WATER IN SOUTHWESTERN WISCONSIN

Richard S. Sartz

In 1961 several different species of coniferous trees were planted on the Coulee Experimental Forest, in southwestern Wisconsin's "Driftless Area." One objective of the plantings was to find out how they might change the hydrologic properties of the soil, a loessal silt loam that had been in continuous agriculture for about 100 years. The area has a long history of soil erosion and flash floods, and when we began the study we thought that tree planting might be needed to control runoff and erosion on steep, eroded slopes of the area. This paper gives the results after 13 to 14 years of tree growth.

PREVIOUS WORK

How trees alter the properties of agricultural soils has been studied widely over the years. Formation of a litter layer is one obvious effect, and the role of litter in runoff prevention was the subject of much early research (Lowdermilk 1930, Kittredge 1940, Rowe 1955, Sartz 1963). In more recent appraisals, Mader and Lull (1968) and Sartz (1969) both questioned the importance of the *amount* of litter, the latter concluding that protecting the soil from raindrop impact was its most important function.

Regarding the surface soil, Billings (1938), who studied old field pine stands of different ages in North Carolina, found that organic matter increased substantially and bulk density decreased substantially between the 13th and 21st years of growth. These trends continued through the 110th year. In Ohio, Harold (1961) reported that after 20 years of pine growth the "air space porosity" in the top 8 cm of silt loam soil had increased from 3 to 9 percent. Byrnes and Kardos (1963) reported that, other than surface organic matter accumulations and rooting habits, there were no major differences in the physical properties of three types of soil under old field and 20-year-old planted red pine in Pennsylvania.

Wilde (1964) reported little change in the organic matter content of sandy or sandy loam soils in Wisconsin pine plantations less than 20 years old; and on loessal soils in Illinois, Rolfe and Boggess (1973) found more soil organic matter and higher surface soil bulk density in old fields than in 30- to 35-year-old shortleaf pine plantations. However, the old field vegetation in their study included hardwood trees as old as 40 years.

A partial assessment of the effect of the Coulee Experimental Forest plantings on soil and water variables has already been made (Sartz and Harris 1972). After 10 years of growth we found no change in soil bulk density under larch and red pine plantations, but the litter layer was twice as heavy in the larch as in the red pine plantings or in unplanted controls. Both species were already depleting twice as much soil water as the old field vegetation on unplanted plots.

THE PLANTINGS

The trees were planted on 0.2 hectare plots at three different sites: an upper north slope of 10 percent; a lower north slope of 25 percent; and a middle south slope of 25 percent. The soil on all sites is a loessal silt loam or a mixture of loess and sand (Typic hapludalfs of the Dubuque, Fayette, and Gale-Hixton series). The lower

north slope site was former pastureland that had never been plowed, but the other two sites were fields that had been under cultivation for 100 years or more. The upper north slope ("ridgetop") site had been in corn and the south slope site in hay the year before planting.

The trees were planted in the spring of 1961 on small bench terraces made with an angle dozer (Stoeckeler 1962). Spacing was 2 by 2 m, with 500 trees per plot. The species evaluated were eastern white pine (*Pinus strobus* L.); red pine (*Pinus resinosa* Ait); white spruce (*Picea glauca* Voss); and European larch (*Larix decidua* Mill.). The red pine planting stock was 2-1, the larch 2-0, and the white pine and spruce 2-2.

The soil and water variables were also measured on one unplanted control plot at each site. These developed into "old fields" during the course of the study. The volunteer vegetation was primarily Kentucky bluegrass (*Poa pratensis*); goldenrod (*Solidago* spp.); wild carrot (*Daucus carota*); and timothy (*Phleum pratense*). The lower north slope plot had no timothy, and after a few years, blackberries (*Rubus* spp.) invaded this plot. Plants and litter completely covered the soil on all these plots.

SAMPLING DESIGN AND METHODS

Design

The soil variables were: litter accumulation; bulk density at two depths (0 to 8 and 8 to 15 cm); nitrogen and organic carbon content at two depths (0 to 4 and 4 to 8 cm); and seasonal soil water depletion in a 1-meter soil mantle. Water content of the snowpack was also evaluated.

To find out how the variables might change with tree growth they were measured at predetermined intervals over the years, starting when the plots were still essentially in an open field condition. Litter, soil bulk density, and soil nitrogen and organic carbon were measured three times (5-year intervals); water depletion, four times (2- to 5-year intervals); and snow accumulation, five times (2- to 4-year intervals). The sampling interval for water depletion and snow accumulation varied because of seasonal weather constraints.

Periodic sampling of the litter and soil required a design that would preclude sampling the same spot more than once. Accordingly, a block of 10 trees by 10 trees in the center of each planting was used as a sampling grid, with each inter-tree space (termed a "sampling block") being assigned a number from 1 to 100. The sampling blocks to be used for each set of samples for each variable were assigned at the beginning of the study, and were mechanically spaced within the 100-sampling block grid. Litter sampling required 10 blocks per set, soil sampling, 5 blocks per set. The unplanted control plots were sampled in the same way, except that the sampling grid was marked with numbered stakes.

Soil bulk density was sampled in the late summer or fall, and litter and soil nitrogen and organic carbon in early spring of the following year; thus, all were sampled at the same stage of tree growth.

Sampling on the planted plots was complicated by the planting furrows, which produced three different soil conditions: the furrow; the overturned furrow slice; and the undisturbed area. I decided to sample litter and bulk density in both the furrow and the undisturbed area. The furrow was sampled at one point (midway between trees in the same row) and the undisturbed area at two (midway between trees in adjacent rows and midway on the diagonal between trees in adjacent rows and columns). Nitrogen and organic carbon were sampled only on the undisturbed area and only on the pine and open plots at the middle and lower slope sites.

Soil water depletion was determined from neutron measurements near the center of the sampling grid. Control plots were sampled at two points 6 m apart, planted plots at two *pairs* of points 6 m apart. The pairs consisted of one point .6 m from a tree and one 1.4 m from a tree. The purpose of the pairs was to see if the amount of water depletion differed at the two distances, and if so, how long the difference might persist as the trees grew.

Snow accumulation was measured on a single transect near the center of each plot. Depth was measured at 10 points, 1 m apart, and water content at 5 points, 2 m apart.

Methods

Surface organic matter was sampled with a 30- by 30-cm frame lowered to the ground from a vertical position above the plot. The litter, F-layer and dead standing herbaceous vegetation inside the frame were included in the sample. The samples were collected in paper bags and air dried before weighing.

Soil bulk density was determined from 300 cc (7.3 by 7.1 cm) undisturbed cores, and soil nitrogen and organic carbon from 21 mm diameter tube sampler cores. The latter were taken at litter sampling points. Two cores were taken at each point, and the cores from all points on a plot were composited. Thus, one composited sample consisted of 20 cores (2 times 10 sampling points). Nitrogen content was determined by the Kjeldahl method, and organic carbon content by the dichromate oxidation method (Mebius 1960).

Soil water depletion was determined from water content measurements made with the neutron meter at three depths: 30-, 60-, and 90-cm. Seasonal depletion was assumed to be the difference between early spring and late summer water contents.

Snow depth and water content were measured with the Mt. Rose snow tube and tubular scales. The measurements were made at the estimated time of maximum snow accumulation--usually late February or March--in the years when a continuous snowpack built up.

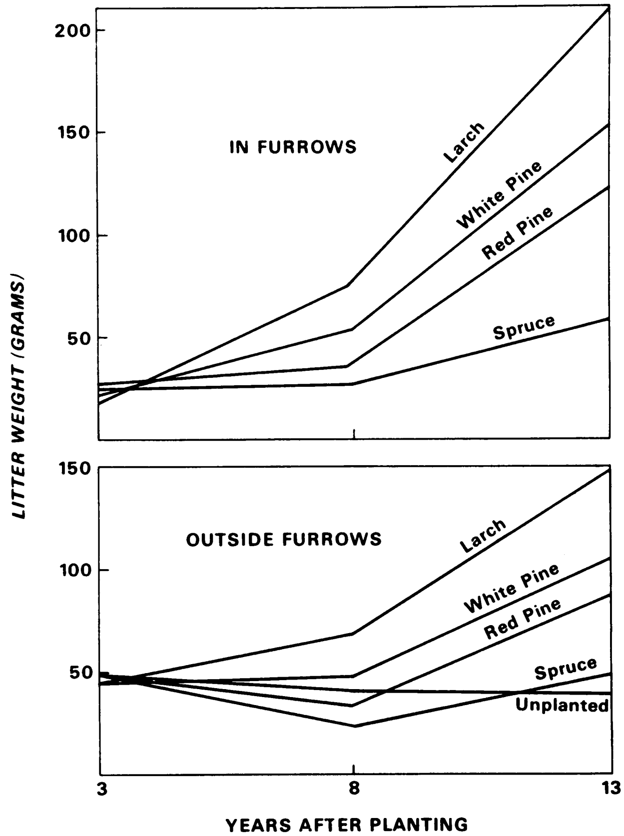

Figure 1.--*Mean litter weight in and outside planting furrows.*

RESULTS

Litter

The first litter sample, taken the third year after planting, consisted mostly of dead grass and weeds, except for varying amounts of old cornstalks in the ridgetop samples. Individual sample weights varied greatly, depending upon the presence or absence of individual heavy stalks--such as mullein. Regardless of weight, the litter completely covered the ground at most sampling points outside the furrows. However, it was still sparse in the furrows (fig. 1).

Five years later (8 after planting) the furrows of the pine and larch plots showed an increase in litter, but the area outside the furrows in the red pine and spruce plots showed a decrease from the previous sample (fig. 1). The latter reflects a decrease in herbaceous growth with increased shading of the plots.

Eight years after planting mosses had started to come in on the more shaded spots, especially in the furrows, and live moss was included in the litter sample where it could be separated from the mineral soil. Cornstalks, common on ridgetop plots in the first sample, were not found in the second. Bluegrass was the predominant cover on most plots, with wild carrot and golden rod stems making up a large part of the weight in some samples. However, litter on the larch plots was mostly from needle fall, which produced a net increase in litter in both the furrow and unfurrowed samples (fig. 1). The pine canopies had started to close and the larch canopy was almost completely closed, except where trees had died. Mean tree heights ranged from 1.3 m for spruce to 5.9 m for larch (table 1).

Table 1.--*Tree heights*[1] *on three sites at time of litter and soil sampling*
(Meters)

Species	Ridge			North			South		
	1964	1969	1974	1964	1969	1974	1964	1969	1974
White pine	1.1	2.4	6.8	1.6	3.9	8.7	1.4	3.7	7.5
Red pine	.9	2.5	6.1	1.1	3.1	6.9	1.0	3.0	6.8
Spruce	.6	1.3	2.4	.8	2.4	5.6	--	--	--
Larch	1.6	5.5	[2]11.0	2.0	5.9	[2]12.0	--	--	--

[1]From 10 trees on each plot.
[2]Estimated from general height of the plantation, rather than individual trees.

By the 13th year, the litter on all planted plots was heavier than on the unplanted controls except for the ridgetop spruce plot in which the canopy was not yet closed. The larch litter formed a continuous mat--in places as much as 4 cm thick. White pine litter was also thick. However, the white pine was pruned twice (in the fifth and ninth years after planting) for blister rust control, and the needles from the pruned branches became part of the litter. So the white pine litter was probably heavier than it would have been without pruning. The litter on both the larch and white pine plots had been partially intermixed with the soil by earthworms.

Neither the red pine nor the spruce needles formed a continuous soil cover, but cones were common. Dead needles that were unavoidably dislodged from the lowest five whorls of the red pine during sampling may have increased variation in the red pine samples. Moss was still common on the ridgetop spruce plot, but grew only in scattered patches of sunlight under the more closed canopy of the north slope spruce plot.

Differences in litter accumulation at 1.0 and 1.4 m from the trees were evident in the 8th year sample, and obvious in the 13th year sample (fig. 2).

The litter sampling method was designed to give point values for comparison among cover types rather than unbiased estimates of mean litter weight on the plots. However, the sample taken midway between trees in adjacent rows may give a reasonable estimate of mean litter weight on the plots. Assuming this, I computed weight per acre to allow comparison with results from other studies. The mean values 13 years after planting for all plots sampled were, in metric tons per acre: larch, 6.36; white pine, 4.53; red pine, 3.75; spruce, 2.13; and unplanted, 1.61. For 18-year-old stands in New York, Day (1940) reported values of 5.49 for white pine, and 5.73 for red pine.

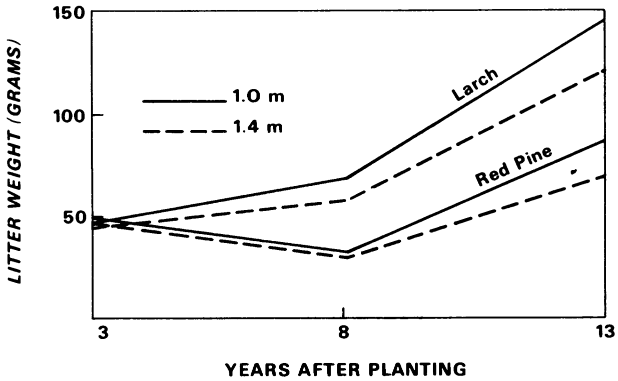

Figure 2.--*Mean larch and red pine litter weight at 1.0 and 1.4 m from trees.*

Soil Bulk Density

In general bulk density of the top 8 cm of soil seems to have decreased, both on planted and unplanted plots. However, great variation in the samples (coefficients of variation were as high as 17 percent) made the results inconclusive. Since the values for the two undisturbed positions on planted plots agreed closely, I combined them for an analysis of differences (table 2). There appeared to be more change in the first 5-year period than in the second, more in furrows than on undisturbed areas, and more on ridgetop plots than on the others. A difference by sites is not surprising, since bulk density was different initially on the three sites (table 3).

Perhaps the most convincing evidence of a real bulk density change in the 0-8 cm sample was the apparent lack of change in the 8-15 cm sample (table 3).

Table 2.--*Change in bulk density in the top 8 centimeters of soil on three sites*
(Grams per cubic centimeter)

Site and species	Undisturbed[1] 1963-1968	Undisturbed[1] 1968-1973	Furrows[2] 1963-1968	Furrows[2] 1968-1973
Ridge:				
White pine	-.10*	+.05	-.05	-.01
Red pine	-.10*	-.01	-.09*	.00
Spruce	-.05	-.08*	+.03	-.13*
Larch	-.06*	+.01	-.10	.00
Mean	-.08	-.01	-.05	-.04
Unplanted	-.07	.00	--	--
North:				
White pine	+.01	+.03	-.11*	-.01
Red pine	+.04	.00	-.03	-.09*
Spruce	+.05	-.10*	-.01	-.07
Larch	-.10	+.09*	-.04	-.07
Mean	.00	.00	-.05	-.06
Unplanted	.00	-.11*	--	--
South:				
White pine	-.01	+.02	-.10	+.02
Red pine	-.04	-.02	-.06	-.02
Mean	-.02	.00	-.08	.00
Unplanted	+.08*	-.10*	--	--

[1]n = 10
[2]n = 5
* Significant at 5 percent level as tested by "T".

Table 3.--*Mean bulk density of planted plots at two depths and three sites*[1]
(Grams per cubic centimeter)

Site	Sampling position	Years after planting: 3	8	13	10-year difference
		0 to 8-cm Depth			
Ridge	Undisturbed	1.15	1.08	1.07	-.08
	Furrow	1.24	1.19	1.15	-.09
North	Undisturbed	1.01	1.00	1.01	.00
	Furrow	1.26	1.21	1.15	-.11
South	Undisturbed	1.30	1.28	1.28	-.02
	Furrow	1.40	1.32	1.32	-.08
		8 to 15-cm Depth			
Ridge	Undisturbed	1.22	1.24	1.26	+.04
	Furrow	1.34	1.34	1.35	+.01
North	Undisturbed	1.18	1.18	1.15	-.03
	Furrow	1.36	1.33	1.37	+.01
South	Undisturbed	1.38	1.38	1.38	.00
	Furrow	1.42	1.39	1.43	+.01

[1]The ridge and north sites had 40 undisturbed and 20 furrow samples; the south site 20 undisturbed and 10 furrow samples.

Soil Nitrogen and Carbon

Because the data for separate sampling positions and depths showed no readily apparent trends, I combined them for further study. The measured values for both elements decreased on all north slope plots and on the south slope white pine plot, but increased on the south slope red pine and unplanted plots (table 4). Whether the differences reflect real soil changes or sampling error is debatable. The nature of the data precluded statistical testing.

Table 4.--*Mean nitrogen and carbon content of surface 8 centimeters of soil on two sites*
(Percent)

Site and species	Nitrogen: Years after planting: 3	8	13	Carbon: Years after planting: 3	8	13
North:						
White pine	0.260	0.204	0.202	5.8	4.9	4.4
Red pine	.218	.186	.195	5.0	4.8	4.1
Unplanted	.268	.239	.202	5.8	5.3	5.4
South:						
White pine	.064	.062	.053	1.4	1.8	1.2
Red pine	.092	.118	.124	1.9	2.6	2.7
Unplanted	.124	.236	.223	2.6	6.1	5.2

Soil Water Depletion

Three years after planting, when the first soil water measurements were taken, planted plots were still depleting about the same amount of water as the unplanted controls. By the 8th year, however, most planted plots were depleting much more than the controls; and by the 14th year, there were 2- to 3-fold differences (table 5). The ridgetop spruce plot did not conform to the general pattern, probably because of shallower soil. Although it is adjacent to the control, it is downhill from it on a steeper grade where erosion losses over the years of cultivation would have been greater. The canopy was still open on this plot, and the trees were less than half as tall as the spruce on the north site (table 1).

Measurements taken in the 10th year on the red pine and larch plots and in a natural oak-hickory saw-timber stand (Sartz 1972b) provide a 2-year interval comparison of depletion by the plantations with depletion by a natural hardwood stand growing on similar north slope sites. Depletion was about the same in the 8th year of plantation growth, but plantation depletion was greater in the 10th and 14th years (table 6).

The small 12th-year depletion differences are misleading (table 5). In years of high growing season rainfall (280 mm fell in July-August of the 12th year compared with 105-155 mm the other years) seasonal depletion, which is the difference between the amounts stored in the soil in the spring and fall, does not give a good index of comparative water use.

Snowpack

The amount of snow accumulation, as measured midway between rows of trees at time of maximum accumulation, was not clearly affected by tree species up to the 10th year after planting (table 7). Mean snowpack water content on planted plots was greater than on open plots on the ridge and south sites, but about equal on the north site. However, the trees affected the pattern of melt within the plantations. This was very evident during snowmelt in 1975. There were still snow accumulations as deep as 50 cm between trees from crown dumping or shading when bare ground was already showing around the trees. These accumulations were deeper on the two north slope plots than on the south slope plot, and were deepest on spruce plots. Among planted plots, the snow surface was most even in the larch.

Table 5.--*Water depletion in a 1-meter soil mantle on planted and unplanted plots at three sites*

(Centimeters)

Site and species	Years after planting: 3	8	12	14
Ridge:				
White pine	7.6	5.9	3.5	11.1
Red pine	8.0	8.9	3.0	12.0
Spruce	9.2	6.1	1.2	5.4
Larch	9.0	9.3	8.1	15.0
Unplanted	7.0	5.1	1.3	6.3
North:				
White pine	6.8	7.9	3.0	11.8
Red pine	8.1	8.1	1.7	12.1
Spruce	10.6	7.1	1.3	9.2
Larch	5.3	9.0	1.6	10.2
Unplanted	10.7	3.7	.6	3.5
South:				
White pine	12.6	8.7	7.6	11.2
Red pine	11.1	8.7	8.0	11.8
Unplanted	11.3	4.8	1.5	4.5
Mean:				
White pine	9.0	7.5	4.7	11.4
Red pine	9.0	8.5	4.3	12.0
Spruce	9.1	6.6	1.3	7.3
Larch	7.2	9.2	4.9	12.6
Unplanted	9.6	4.5	1.1	4.7

Table 6.--*Water depletion in a 1-meter soil mantle by planted red pine and larch compared to depletion by natural hardwoods*

(Centimeters)

Vegetation	Years after planting: 8	10	12	14
Red pine	8.1	12.8	1.7	12.1
Larch	9.0	11.8	1.6	10.2
Hardwoods	8.6	10.5	2.7	7.8

Table 7.--*Snowpack water content by species and sites 10 years after planting*

(Millimeters)

Species	Ridge	North	South
White pine	155	147	109
Red pine	170	163	137
Spruce	193	152	--
Larch	175	160	--
Mean	173	156	123
Unplanted	142	157	91

The amount of snow accumulation was also affected by site, as previously reported (Sartz 1972a).

DISCUSSION AND CONCLUSIONS

This study was planned to tell us how different tree species might change the soil as they grow from small planted seedlings to dense plantations. When we began the study we thought that tree planting might be an effective flood prevention practice on steep, eroded slopes of the area. Since then, however, we have found that maintaining a soil cover is the real key to runoff control; and that simply retiring land from active agriculture reduces its runoff potential drastically (Sartz 1970, 1975, Sartz and Tolsted 1974). Because of this, some of the things learned from this study may now be "after the fact," so-to-speak. Nevertheless, the information adds to the general pool of knowledge on forest-soil relationships.

The much greater amounts of litter that built up under larch would seem to make it a preferred species for watershed management planting; however, the additional litter may have no value in preventing rainfall runoff (Mader and Lull 1968). It may have value in reducing soil freezing, which could reduce snowmelt runoff. However, this has yet to be demonstrated experimentally. The temporary litter decrease during the transition from grasses and weeds to tree needles (fig. 1) is interesting, but probably of little importance to the runoff process.

The plantations are not yet old enough to have reduced soil bulk density much; but this also may not be important, since the soil is already absorbing most of the rainfall anyway.

By the 10th year, the pine and larch plantings were using substantially more water from the top meter of soil than the unplanted controls, and a little more than a natural hardwood forest. The additional water depleted by the trees can reduce flood runoff potential from summer storms because it enlarges the soil water storage reservoir. On the other hand, this may reduce the contribution to ground water, springflow, or stream base flow, which would have a negative effect on water production.

Depletion values reflect rainfall gains as well as evapotranspiration losses. So the values would vary from year to year, even with an unchanging vegetation. Thus, in the 12th year (1973) the high growing season rainfall tended to mask the losses from evapotranspiration. Differences in the length of the depletion period would also affect the amount of depletion measured from one year to another. These are inherent weaknesses in the depletion method of assessing comparative water use by different vegetations.

The snow sampling method used was not adequate for determining mean snow accumulation in young forest plantations. The uneven distribution of snow caused by interception, crown-dumping, and irregular shading, requires a much more intensive sample for an unbiased estimate of the true snow cover. And even with an adequate sampling design, getting good measurements in unpruned stands would be difficult because of access problems.

When this study was conceived I had planned to follow changes in the variables with tree growth for longer than 14 years. However, after finding that tree planting is not really needed to prevent runoff and erosion in the Driftless Area, I decided to terminate the study with this report. The second objective of the plantings--to determine the adaptability of several species to different sites of eroded loess soil--has been partially met; but further observations on growth should be made at appropriate intervals to assess the wood products potential over a longer period of time.

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Changes in litter weight, soil bulk density, soil nitrogen and organic carbon contents, soil water depletion, and snowpack accumulation were evaluated over 14 years of plantation growth on three different sites. The species studied were white and red pines, white spruce, and European larch, along with unplanted controls.

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