American
Society of
Agricultural
Engineers

Paper No. 912136
AN ASAE MEETING
PRESENTATION

IMPACT OF POPLAR TREE BUFFERS ON RIPARIAN ECOSYSTEMS

by

Louis A. Licht, Assoc. Research Scientist
Jerald L. Schnoor, Professor
The University of Iowa
Iowa City, Iowa 52242

Mark F. Madison, P.E.
CH2M Hill
Portland, Oregon

Written for presentation at the
1991 International Summer Meeting
sponsored by
THE AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Albuquerque Convention Center
Albuquerque, New Mexico
June 23-16, 1991

SUMMARY:

Densely planted rows of Populus spp. trees are being grown in riparian zones between creeks and row-cropped fields. The growth results and impact on the near surface groundwater will be summarized following 3 growing seasons.

KEYWORDS:

Buffer Strips, Non-point Source Pollution, Nitrate, Riparian Ecosystem, Populus spp.

2950 Niles Road
St. Joseph
Michigan
49085-9659 USA
Voice: 616/429-0300
FAX: 616/429-3852

IMPACT OF POPLAR TREE BUFFERS ON RIPARIAN ECOSYSTEMS

by

Louis A. Licht, Associate Research Scientist, P.E.
Dept. of Civil and Environmental Engineering
University of Iowa, Iowa City, IA. 52245

Jerald L. Schnoor, Professor
Dept. of Civil and Environmental Engineering
University of Iowa, Iowa City, IA. 52245

and

Mark Madison, P.E.
CH2M Hill
Portland, OR.

KEYWORDS:
Nitrate, Poplar, Non-point Source Pollution, Buffer Strip, Groundwater Quality, Riparian Ecosystems, Biomass.

ABSTRACT

This research summary describes the growth and measured impacts of a perennial buffer strip densely planted with *Populus spp.* (poplar) trees in a riparian corridor between a creek and row-cropped land. The tree's physiological attributes that contribute to a harvested value include cut-stem rooting, fast wood growth, resprouting from a stump, phreatophytic roots, and a high protein content in the leaves. Measured data document that nitrate is removed from near-surface groundwater by root systems and that the nitrogen uptake is present as protein in the biomass. The wooded riparian strip impacts the local agricultural ecosystem by reducing fertilizer nutrients infiltrating to surface water, diversifying wildlife habitat, intercepting eroded soils, and providing a wind break. This idea is a potential technique for managing non-point source pollutants created by modern farming practices.

THEORETICAL FRAMEWORK

Literature Basis

There is no specific reference in the literature to poplar buffer strips grown in agricultural riparian zones for both biomass growth and non-point source pollution control. This innovative crop management scheme was based on five underlying concepts summarized by the following literature citations:

1. The impact of conventional row-crop agriculture on the fate and movement of nitrate-nitrogen and sediment has been documented by Alberts et al,1978; Baker,1980; Baker and Johnson,1976; Blackmer et al,1989; Burwell et al,1977; CAST,1985; Kramer et al,1989; NRC,1978; Tisdale,1975.
2. Plant root uptake and metabolism of nitrogen from the soil pore water solution has been documented by Barber,1984; Glass,1989; Gregory,1987; Haynes,1986; Lewis,1986.
3. Poplar reproduction, survival, and growth in riparian or wetland conditions has been documented by Bowmer,1981; Christ et al,1983; Dickman,1983; Ek,1983; Isebrands,1983; Kawase,1981; Mitsch,1986; Zavitkovshi,1983.
4. Buffer strips and the use of riparian areas as a filter for agricultural nonpoint source sediments and chemicals has been documented by Cooper et al,1986; Dillaha,1989; Jacobs and Gilliam,1985; Lowrance,1984, Schlosser and Karr,1989; USDA/SCS,1988.
5. Utilization of plants, specifically trees, for treatment of municipal and industrial wastewater or sludges has been documented by Crites and Reed,1986; Overcash and Pal,1981; U.S. EPA,1981; Urie,1987.

Buffer Concept

The overall purpose of this research is to design and create a prototype wooded buffer strip ecosystem in a riparian corridor bordering a stream flowing through row-cropped land. This research challenges the conventional farming practice of annual row crop tillage in the riparian corridor as the highest and best land use. The collected data is being analyzed to determine if the following two goals could be simultaneously achieved by this buffer:

GOAL 1. Grow a valuable, perennial crop (principally *Populus spp.* wood and leaf material) that is economically competitive with commodity crops now cultured in this agricultural ecosystem.

GOAL 2. Reduce negative ecological impacts from tilled land by intercepting the mass of non-point source nitrates and silts that pass through the riparian corridor and enter surface water resources .

The placement of the prototype tree buffer as theorized in the original concept proposal is schematically shown in Figure 1.

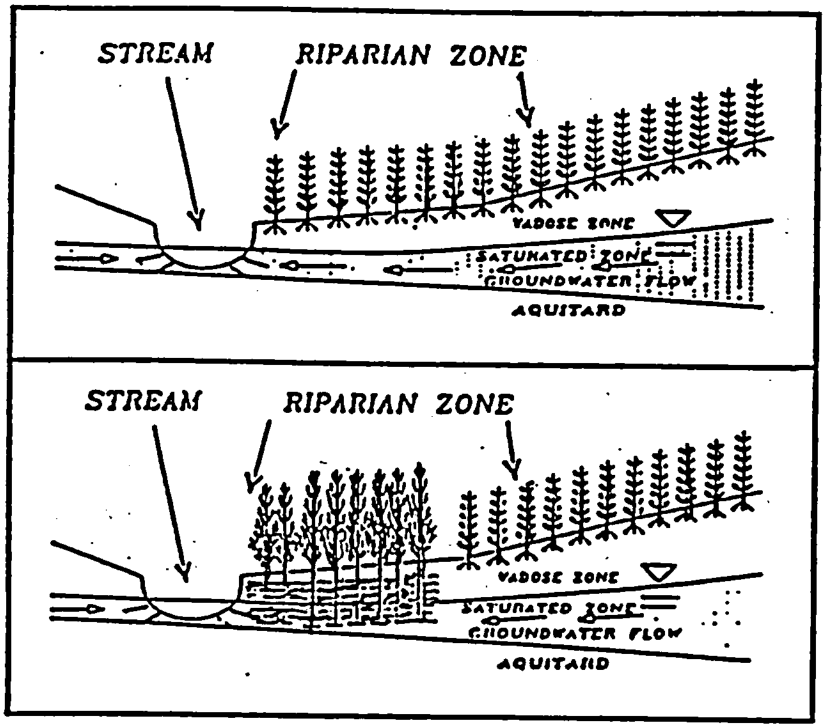

Figure 1: Top Diagram Shows a Conventionally Row Cropped Riparian Zone; Lower Diagram Shows the Growing Prototype, Deep-Rooted Tree Buffer.

PROTOTYPE BUFFER INSTALLATION

The first buffer strip was installed May 17, 1988 at the Amana Society Farms, Amana, IA. The site contained a perennial stream with rotated crops planted up to the creek bank edge. The buffer strip paralleled the creek; it consisted of ten adjoining plots each 3 m by 12 m (10 ft by 40 ft). The treed buffer strip was four rows with an overall width of 3.6 m (10 ft). In contrast to 'normal' hardwood tree spacing that allocates 3.9 to 9.3 m^2 (40 to 100 ft^2) per tree, these poplars were spaced 30 cm (1 ft) apart in the row and 100 cm (40 in) between rows for an area allocation of 0.3 m^2 (3.3 ft^2) per tree in the buffer strip. A 5 m (15 ft) wide fallow strip adjacent to the creek was included as a drive for equipment. The total tree buffer and fallow strip was 0.095 hectare (0.24 acres).

To increase poplar's productive and environmental value, this buffer strip was designed with a dense tree population. The initial planting density is 33,500 trees per hectare (13,200 trees per acre).

An objective of this project was to test an innovative technique to plant unrooted cuttings such that roots develop below the near-surface watertable. It is difficult to culturally control rooting depth when planting a seed or short tree cutting. Roots from most terrestrial plant species normally grow within 50 cm (20 in) of the soil surface to meet nutrient and water needs. This project measures the innovative concept that roots from selected tree species can be intentionally grown to depths that intersect the near-surface water table. There, these roots can remove nitrate-nitrogen from near-surface groundwater.

Selected tree species with preformed root initials located beneath the bark of stems and branches offer the physiological ability to place perennial roots deeper in the soil profile; *Populus spp.* (poplar) is one candidate species. These root initials enable root sprouting from the entire planted stem's buried length. The planting technique used to purposefully grow roots 150 cm (5 ft) deep in the soil profile is shown in Figure 2.

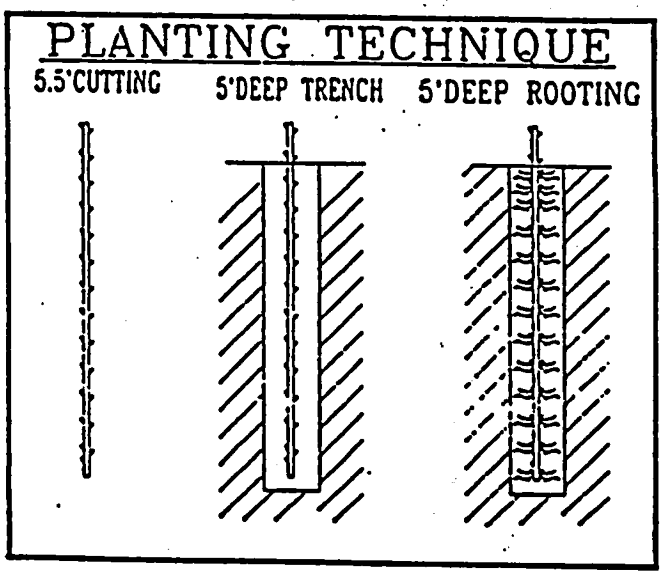

Figure 2: Technique For Growing Roots 150 cm (5 ft) Deep in the Soil Profile.

The entire buffer area was tilled to a depth of 15 cm (6 in) to breakup the topsoil and remove all surface vegetation. One plot was planted with 172 cuttings of Imperial Carolina variety *Populus spp.*, each 1.65 m (5.5 ft) long and vertically inserted in 1.5 m (5 ft) deep trenches dug parallel to the creek using a Ditch Witch® trencher. Other plots were planted with 0.3 m (1 ft) long cuttings manually inserting 0.25 m (10 in) deep at the same population density. No fertilizers or herbicides have been applied to the trees since the buffer installation. Figure 3 shows the following tree planting.

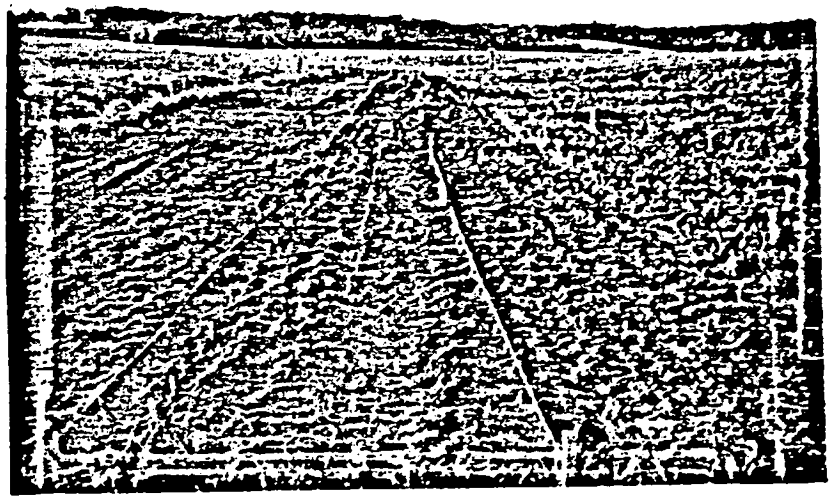

Figure 3: Riparian Buffer Plot Following Planting, 17 May 1988.

Bordering crops have included oats, 1988, and corn, 1989 thru 1991. Ammonia fertilizer was applied at the rate of 150 lb N/ac in spring 1989 thru 1991 to corn planted upgrade from the buffer. In 27 months, the poplar trees planted in 1988 developed into the buffer shown in Figure 4. The buffer planted now bears a striking visual resemblance to the original proposal.

Figure 4: Riparian Poplar Buffer Bordering Row-cropped Farmland, August 1990.

RESULTS

Plant Growth

Populus spp. trees grew well in densely populated, four-row buffers. The 1988 growing season was the driest in recorded Iowa history. In November 1988, the average stem from 0.3 m cuttings weighed an estimated of 39 g, the average stem grown from 1.65 m cuttings was 138.6 g. The average growth rates for the poplar plots in their second growing season are shown in Figure 5, along with their linear least squares regression equation. After two growing seasons the sampled trees averaged over 4.5 m (15 ft) tall. *Populus spp.* had an average growth rate of 5.4 g biomass/tree/day (dry weight basis) during their second 175 day growing season. At this growth rate and this planting density, the poplar buffer strip will yield over 43,500 kg biomass/hectare (40,000 lb biomass/acre) in two growing seasons. At the end of the second growing season, this mass was approximately 20% leaf and 80% stem. There is no significant difference (p>.1) in the growth rates between trees grown from 1.65 m (5.5 ft) deep-rooted poplars or from 0.3 m (1 ft) shallow-rooted poplars.

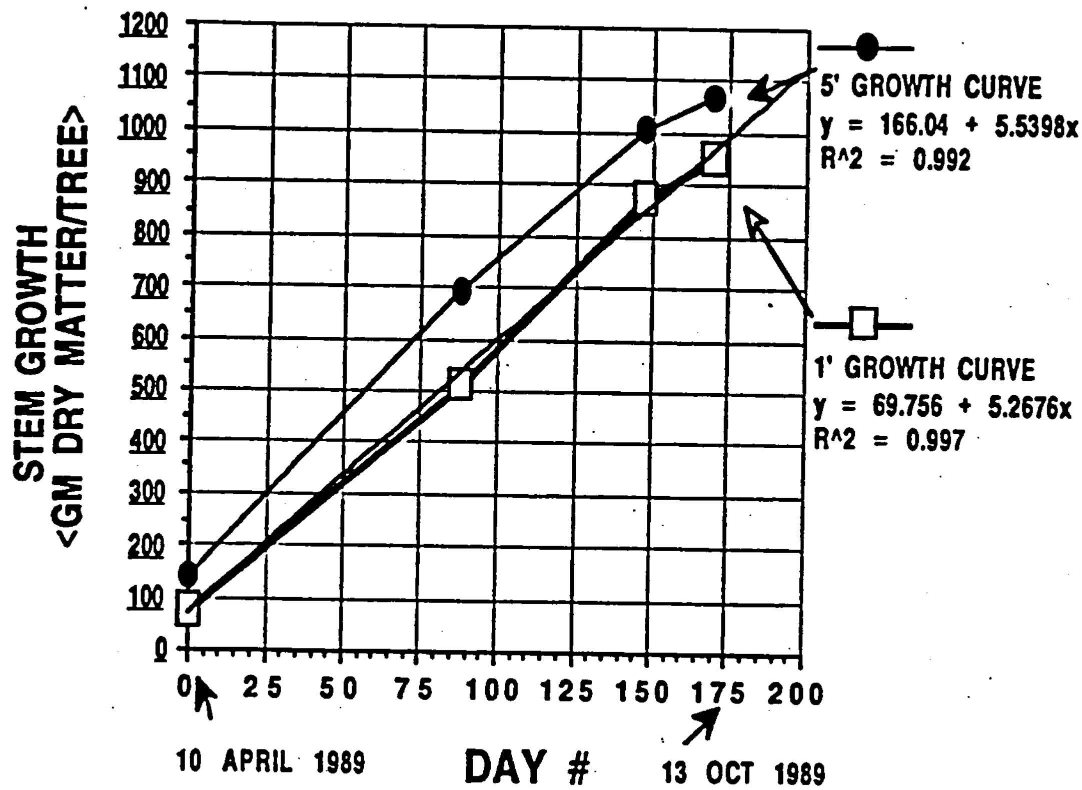

Figure 5: Stem Dry Matter Growth Curves for *Populus spp.* Trees Using 1 ft and 5 ft Long Cutting Stock during the 1989 Growing Season.

On March 17, 1991, 37 trees were harvested from the external row of the deep-rooted plot planted May 17, 1988. The row had a north-south orientation and a western exposure. The height and base diameter data for this tree population are shown in Figure 6. The mean height of the harvested trees is 5.21 m. (17.2 ft); the average base diameter is 5.09 cm (2.03 in).

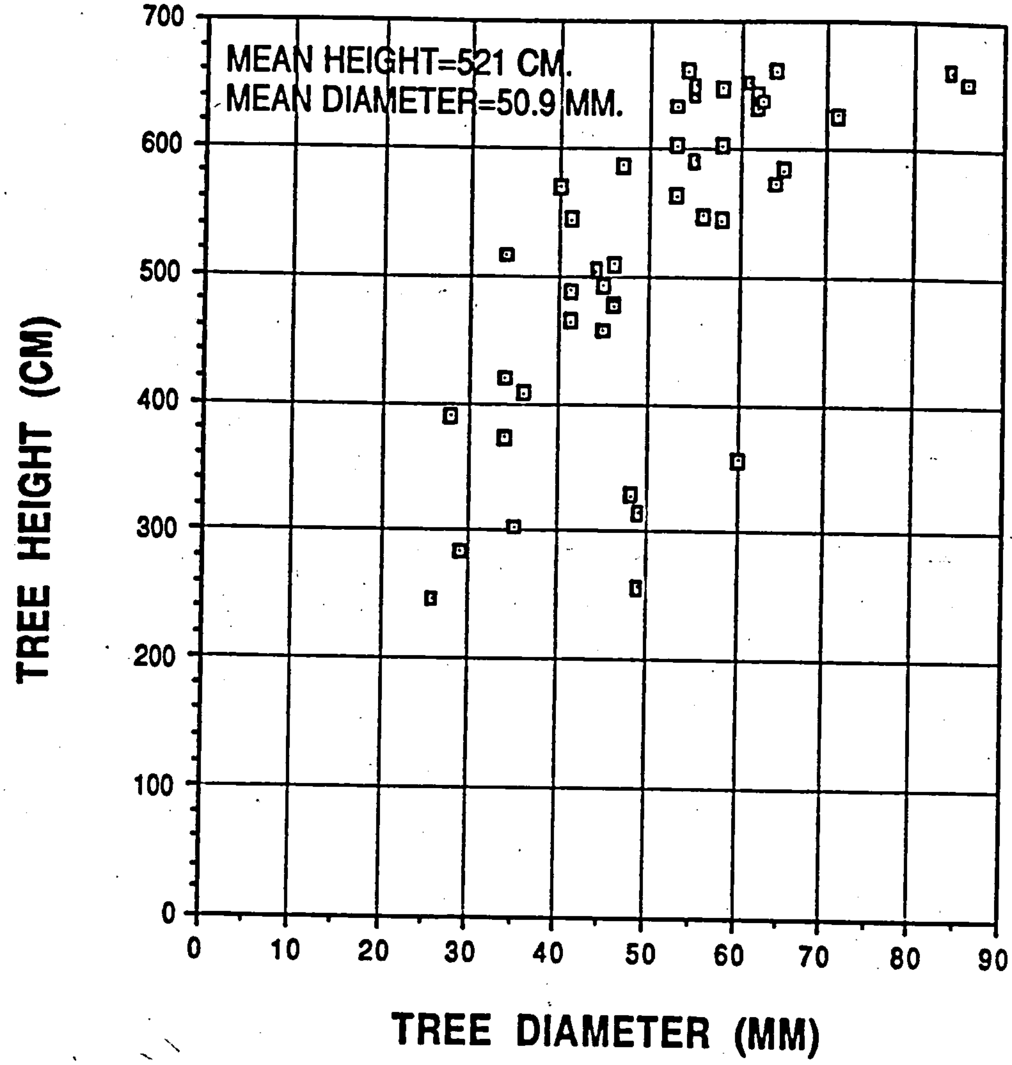

Figure 6: Tree Diameters and Heights of Harvested 34-Month Old Riparian Poplar Buffer Bordering Row-cropped Farmland.

The tree diameter and wet weight for the harvested trees is shown in Figure 7. The harvested trees weighed at the time of harvest had a mean mass of 4.36 kg (9.67 lb). The average dry matter content measured from 6 samples was 55%. The average tree dry matter mass is calculated to be 5.32 pounds in the harvested stem and branches.

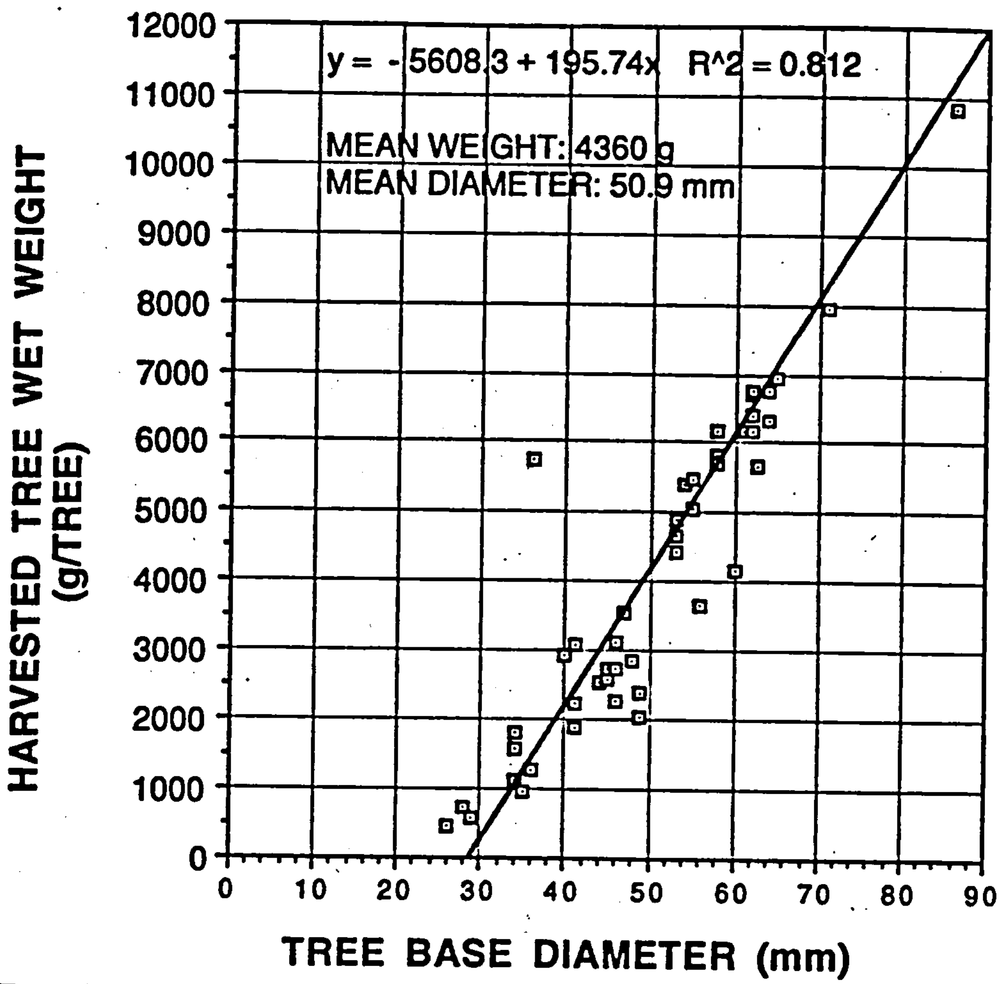

Figure 7: Tree diameters and weights of harvested three-year old poplar grown in a four-row buffer bordering row-cropped farmland.

Coppiced Regrowth

When the trees are cut, coppiced sprouting occurs, meaning new stems regrow from the cambium layer between the bark and the wood in cut tree stumps. This makes repeated biomass harvesting possible while maintaining a vigorous, deep, perennial root system. As a perennial, this tree regrows from well-established roots without replanting and offers a minimum shutdown in nutrient and water uptake abilities. Figure 8 shows the number of shoots coppiced from the stumps cut March 17, 1991. Over 50% of the stumps regrew more than nine shoots with the minimum coppice having two shoot and the maximum coppice having 16 shoots.

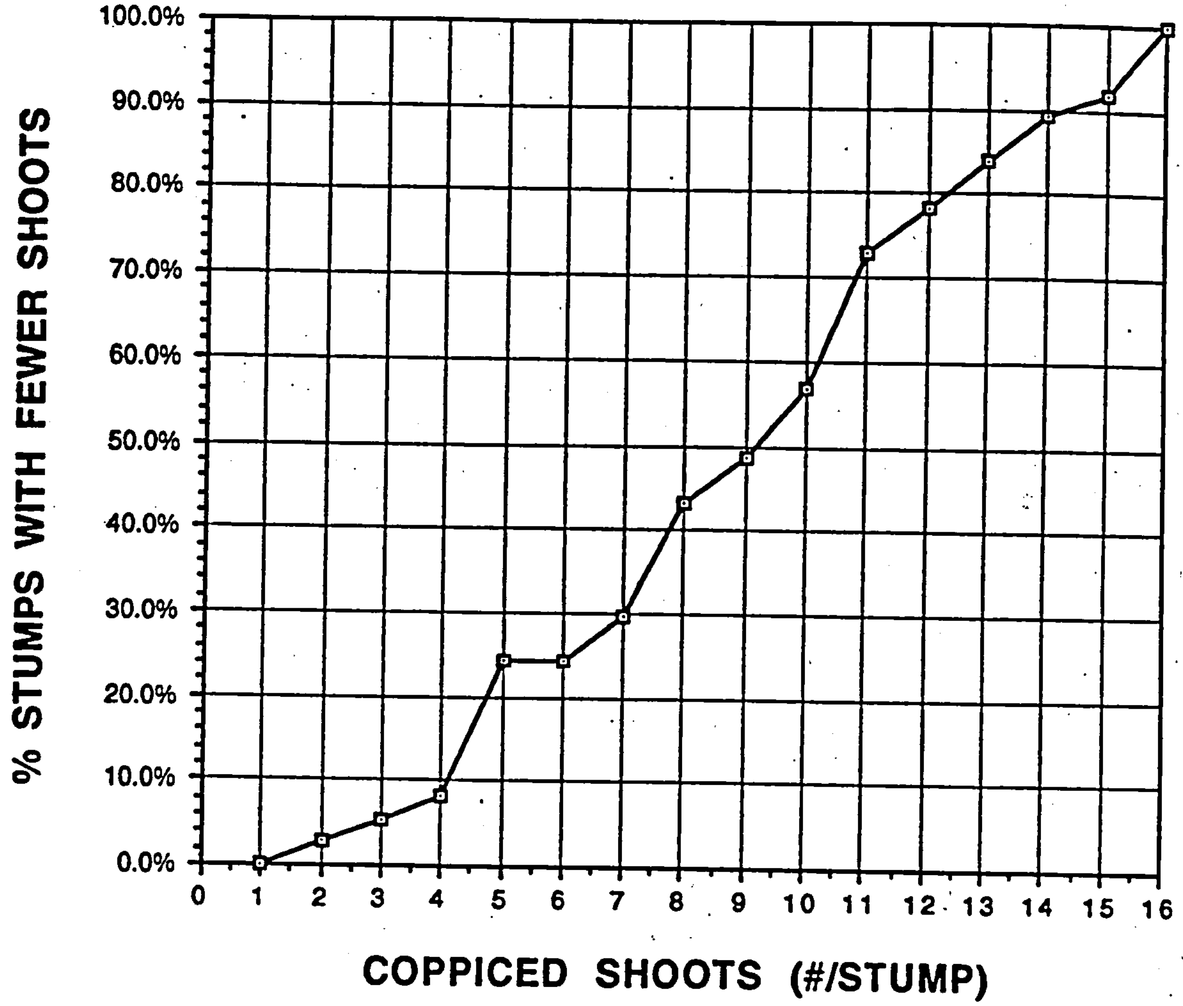

Figure 8: Number of Coppiced Shoots per Harvested Stump.

The height of the tallest coppiced shoot regrown from each harvested tree was measured June 19, 1991. Since harvest, over 50% of the trees have a terminal leader taller than 127 cm (50 inches) as shown in Figure 9. The tallest tree shoot grew 80 inches since the March 17, 1991 harvest. Contrasted to the first-season growth from cuttings, this growth rate is much more vigorous due to the mature root system supporting water and nutrient uptake from the riparian soil pore water. This rate of regrowth ensures that the harvested poplar crop can continue competitive success by achieving dominance in the plant canopy. Because nitrogen is the major essential nutrient for plant growth, this perennial root system also assures minimum shutdown in non-point nitrate-nitrogen removal abilities.

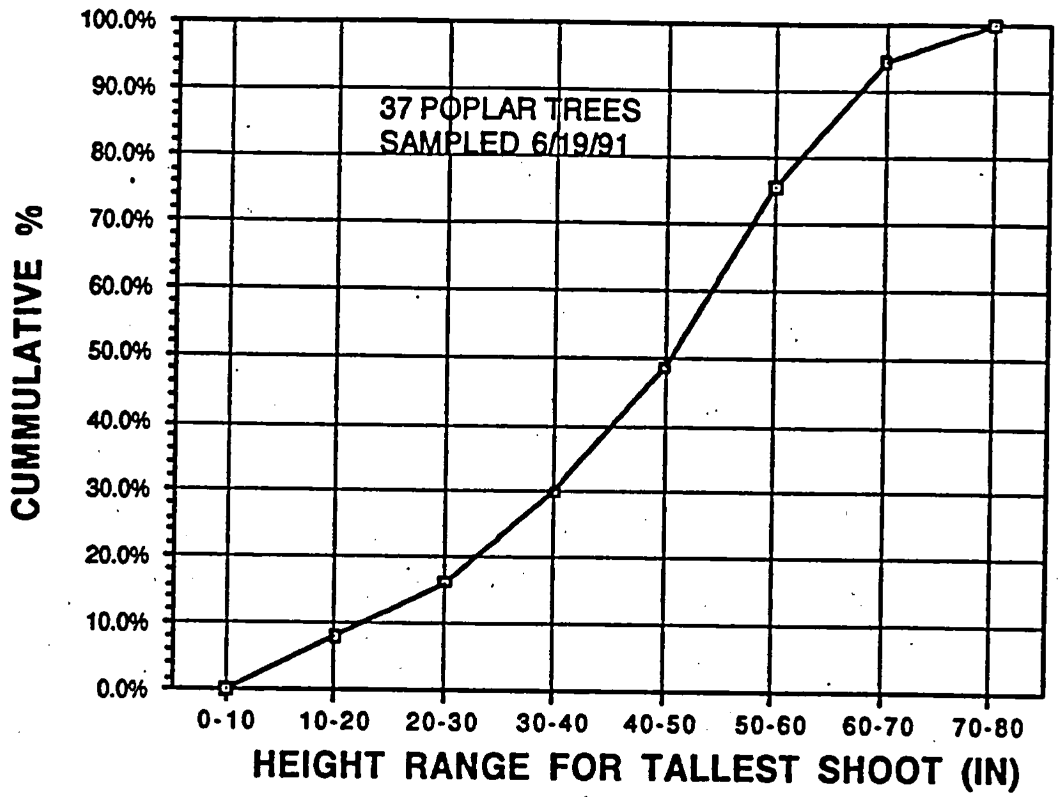

Figure 9: Height of the Tallest Coppiced Shoot from Harvested Poplar Stumps.

This reqrowth did not require tillage or extra expense for replanting. Future harvesting of this buffer strip is scheduled to occur on a biennial or triennial schedule.

Root Placement and Growth

Populus spp. trees can root deep into riparian soils. Poplars formed viable root systems their entire buried length in 150 cm (5 ft) deep trenches by planting 165 cm (5.5 ft) long poplar cuttings. When short cuttings 30 cm (12 in) long are planted 25 cm (10 in) deep, the bulk of the roots penetrated 0.5 m (20 in) in the soil profile following two dry growing seasons.

Results from the first two growing seasons have demonstrated that *Populus spp.* cuttings rooted their entire buried depth when 1.65 m (5.5 ft) cuttings were planted to depths of 1.5 m (5 ft) in riparian trenches. Roots grew from preformed root initials located below the stem's epidermis which emerged the entire buried depth.

The tree root presence and the planting technique significantly impacts the soil profile. For 1 ft cuttings, roots grew primarily within the top 50 cm (20 in) of soil, though there were several thin roots that grew down 6 ft into the soil. The 5.5 ft cuttings produced a dense, viable root system their entire 5 ft buried length in the trench. Figure 10 shows the root development from long cuttings exposed in their excavated trench.

Figure 10: Exposed Roots in Excavated Trench Grown from a 5.5 ft Long Poplar Cutting Planted 5 ft Deep.

Nitrogen in Poplar Stem and Leaf

The sampled poplar trees contained an average of 2.3% nitrogen in the leaf tissue and 0.4% nitrogen in the stem. Nitrogen is taken into the root by uptake of soluble inorganic nitrate or ammonium nitrogen from soil pore water. The plant metabolizes this inorganic nitrogen into proteins, amino acids and other organic molecules. In 1989 each tree removed an estimated nitrogen mass of 10 g/tree during the 175 day growing season for an average uptake of 57 mg/tree/day At this rate, the harvestable stem and leaf in the poplar buffer strip poplars contained an estimated 330 kg nitrogen/hectare (300 lb nitrogen/acre) in two growing seasons.

With the 1989 growing season's progress, the leaf nitrogen concentration on a dry weight basis started at 2.6 % and decreased to 1.97%. The stem nitrogen concentration on a dry mass basis fluctuated between 0.3 to 0.5 % throughout the sampling period. This plant nitrogen was removed from the soil solution nitrogen reserve. Figure 11 shows the estimated change of nitrogen fixed in leaves and stems during the growing season. During 1989, leaf/stem ratio measured from whole-tree harvest averaged 0.25, thus for every pound of stem grown in the second growing season approximately 0.25 pounds of leaf was produced. After two growing seasons, the leaves represent approximately 57% of the nitrogen in the combined leaf and stem mass.

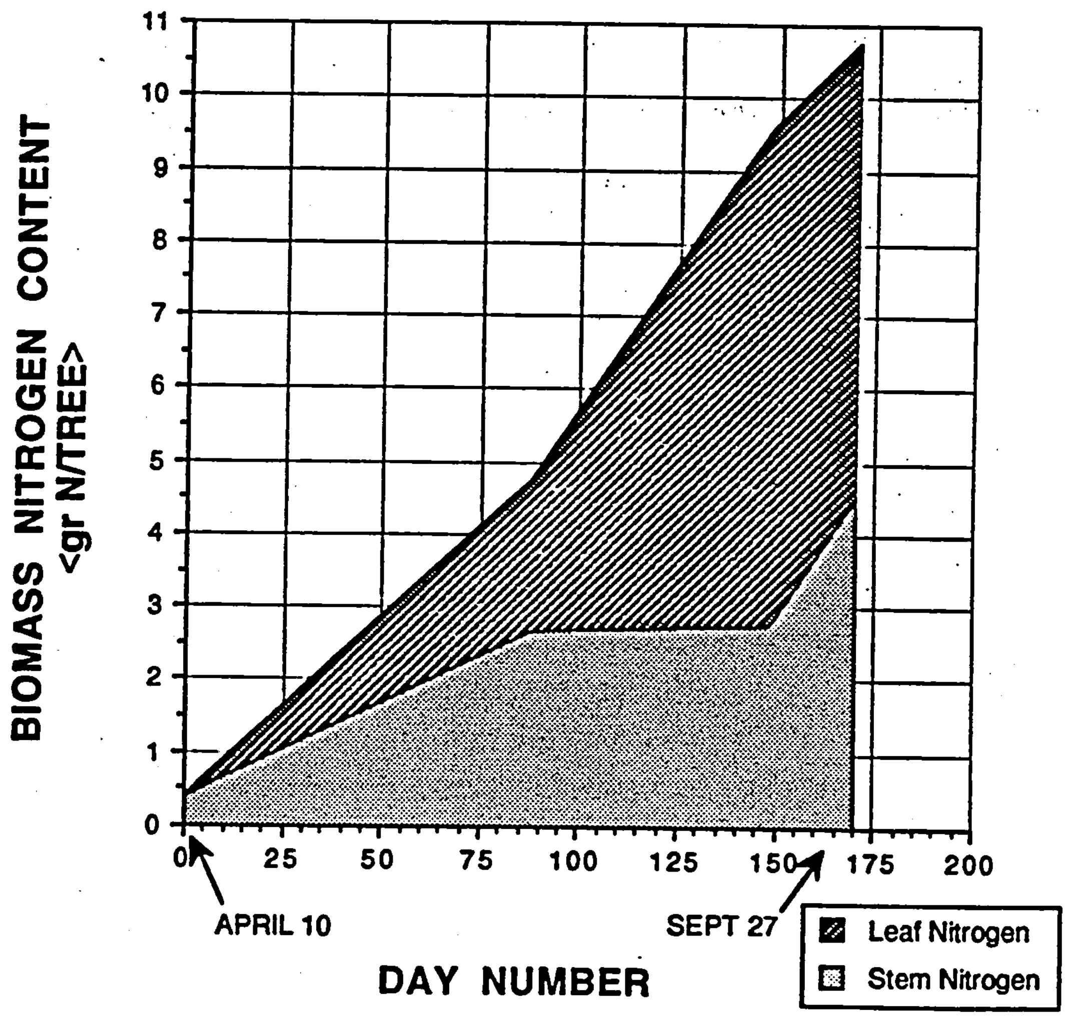

Figure 11:Stem and Leaf Nitrogen Mass per Tree.

There is no statistically significant difference ($p>.1$) for the stem and leaf nitrogen content between 1 ft and 5 ft cuttings. The leaf/stem ratio and the nitrogen content in the stem and leaf provide the basis when planning the nitrogen and carbon management strategy for the site. The strategy for nitrogen removal from the poplar buffer strip may require leaf management. This could be accomplished by total plant removal, fallen leaf removal, or some type of leaf grazing by livestock.

Nitrate-Nitrogen in Soils

Deep *Populus spp.* root systems and the deep-planting method very significantly ($p<.0005$) reduced the nitrate-nitrogen mass in the trenched soil profile. Soils were sampled 1.5 m (5 ft) deep below corn, fallow and the deep planted poplar tree buffer. In contrast to an average nitrate-nitrogen concentration of 25 mg N/kg dry soil in the soil column below conventionally cultured corn, the entire profile below the trees contained an average 2.3 mg nitrate-nitrogen/kg dry soil.

Corn was grown in 1989; anhydrous ammonia fertilizer was applied to the corn land at the rate of 168 kg N/ ha (150 lb N/acre) in March. The means of the analyses for triplicate soil columns sampled October 1989 are shown in Figure 12.

The shape of the nitrate curve for the fallow plot is characteristic of an agricultural soil growing shallow-rooted plants. There is no significant difference ($p>.1$) in the nitrate-nitrogen concentration profiles between the fallow and 1 ft cutting plots.

The nitrogen concentrations below corn in the soil profile show values ranging from 10 to 35 ppm in the top four feet. There is an anomaly in the data for a low nitrate concentration average in the three-foot-deep sample; there is no research data explaining the overall concentrations in the profile. There is a very significant difference ($p<.0005$) between this corn nitrate profile and all other plot treatments. This nitrate difference is attributed to the anhydrous ammonia fertilization in March 1989 followed by microbial nitrification of ammonium to nitrate.

The nitrate-nitrogen samples for the 5 ft deep-rooted trees were taken from soils inside the back-filled trench. The nitrate-nitrogen concentration in the trench planted with the deep-rooted poplar cuttings averages a very constant 2-3 mg N/kg dry soil. The nitrate concentration profile for the 5 ft cutting plot is very significantly different ($p<.0005$) from all other plots.

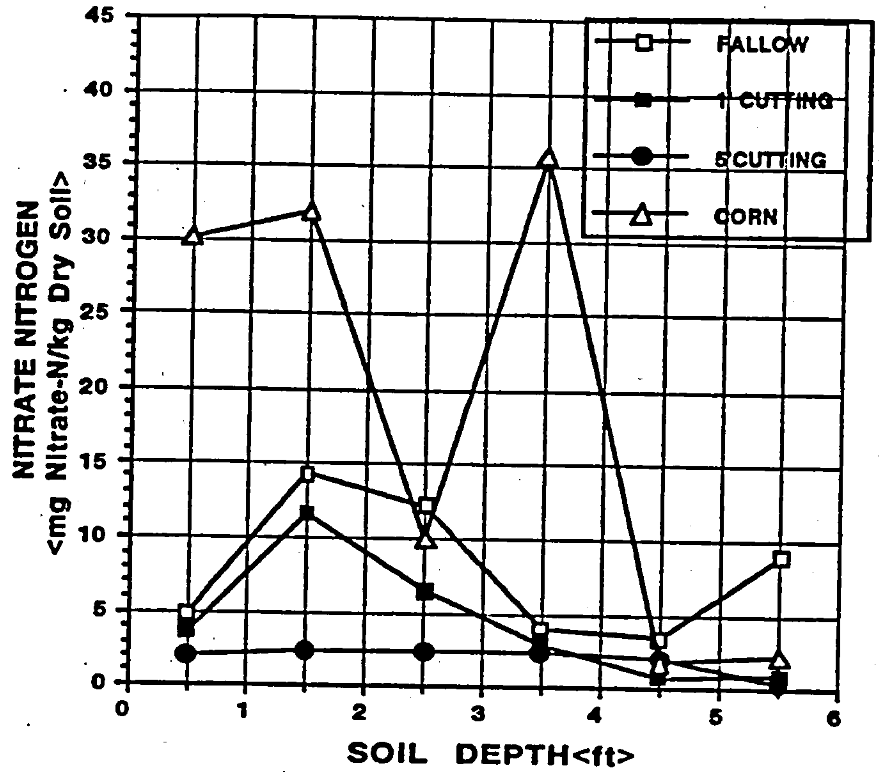

Figure 12: Average Nitrate Concentrations in Plot Soils to 5 Feet Depth, October 1989.

It is apparent that there was nitrate-nitrogen uptake by the tree roots the entire buried cutting depth. This nitrate removal by the deep-rooted cuttings corroborates the nitrate concentrations in piezometer samples.

Nitrate-Nitrogen in Near-Surface Groundwater

Poplar tree roots reduce nitrate-nitrogen in near-surface groundwater. Poplar tree roots reduce nitrate-nitrogen in near-surface groundwater. The mean nitrate-nitrogen concentrations were measured in 200 samples collected from the buffer piezometers between June 17 - September 27, 1990. Based on mean concentrations over the sampling period, shallow-rooted buffers reduced nitrate-nitrogen by 94.7%; deep-rooted buffers reduced it by 97.4%.downgrade from the tree buffers.

Both deep- and shallow-rooted trees decrease the nitrate-nitrogen concentration in water sampled from midplot and downgrade wells. Figure 13. shows season-average nitrate-nitrogen concentrations in water samples from

1.5 m deep corn field piezometers located 2 meters upgrade from the tree buffer, midplot, and 2 meters downgrade; midplot concentrations were reduced 30.5% by the shallow-rooted trees and 96.7% by deep-rooted trees.

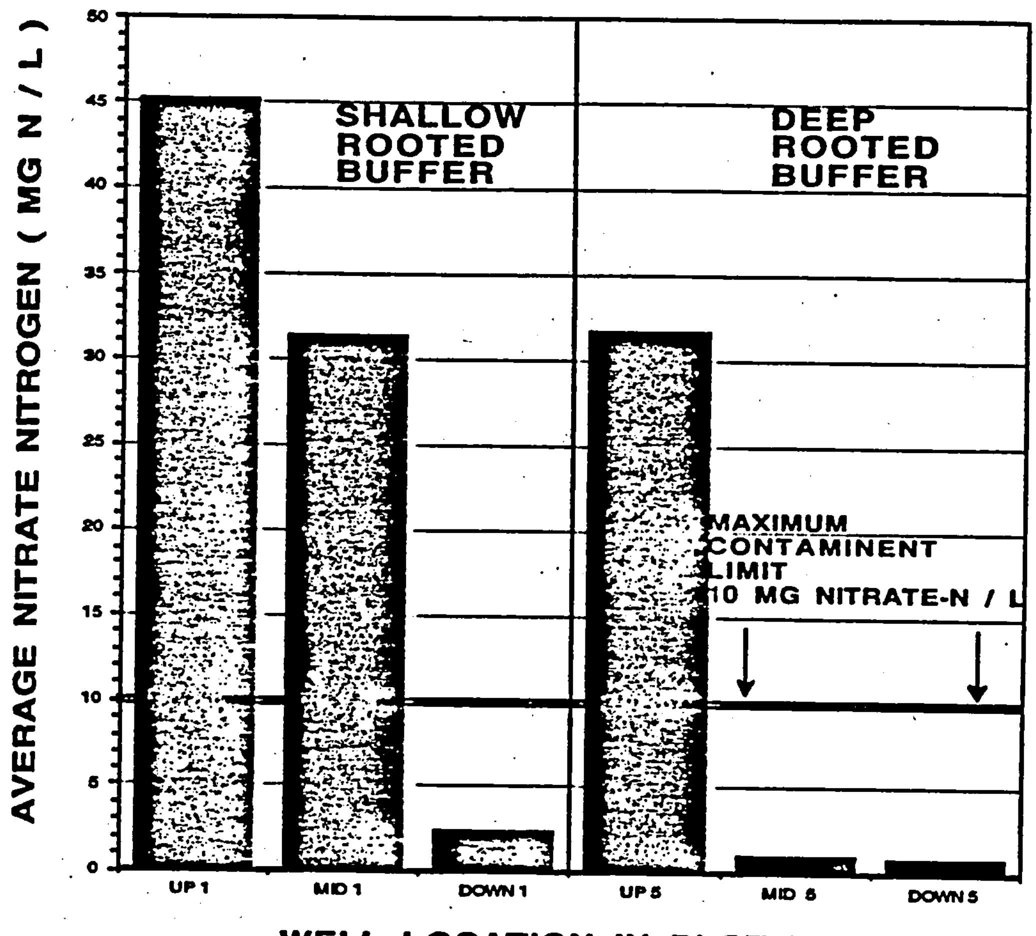

Figure 13: Mean Nitrate-Nitrogen Concentrations in Plot Piezometers, Summer 1990.

The contrast between nitrate-nitrogen concentrations in corn field and tree plot piezometers corroborate the soil nitrate-nitrogen concentration profiles. There is a demonstrated and statistically supported impact of the poplar roots as a nitrate removal mechanism from near-surface groundwater.

CONCLUSIONS

Though this research is still in its embryonic stage of development, the following conclusions have been drawn from data collected at a three-year old poplar buffer growing in Amana, IA.:

1. The *Populus spp.* tree will grow a great mass of stem, leaves, and root when planted in riparian buffer strip configurations. The market for this material will partially determine the value of the buffer.
2. The *Populus spp.* tree roots can be cultured to impact the near-surface groundwater flowing from the field to the stream. Nitrate-nitrogen is removed from the groundwater by combined impacts of root nutrient uptake and anoxic denitrification.
3. The *Populus spp.* tree is capable of achieving dominance in the plant canopy and competing well with weed pressure. Thus, the need for cultivation under the tree-planted zone will not be required. This tree buffer can now better retain the surface soil and intercept surface sediment overflow.
4. The *Populus spp.* trees harvested in the winter will coppice new shoots that grow vigorously and competitively in riparian buffer strip configurations. Thus, it is not necessary for the land owner to replant the buffer in spring following harvest; it is not necessary for the tree-planted acreage to be drained. Being phreatophtic, this plant genera can survive and thrive with a saturated root zone. Thus the potential exists that a farmed pothole, seep, or drainage could contain poplar trees for its primary crop and not require tile line drainage.
5. The *Populus spp.* trees quickly grow vertically. The tree structure and leaf mass produce a dense windbreak with apparent impacts on wind velocities at the soil surface.
6. The riparian corridor planted with *Populus spp.* trees and other perennial plants can quickly develop a more diverse habitat for wildlife.

LITERATURE CITATIONS

•Alberts, E.E., G.E. Schuman and R.E.Burwell, Seasonal Runoff Losses of Nitrogen and Phosphorus from Missouri Valley Loess Watersheds, J. Environ. Qual., Vol. 7, No. 2, pp 203-208, 1978.

•Baker, J.L., Agricultural Areas as Non-point Sources of Pollution. In Environmental Impact of Non-point Source Pollution, Ann Arbor Sci. Publ., Ann Arbor, MI., 1980.

•Baker, J.L. and H.P.Johnson, Impact of Subsurface Drainage on Water Quality. In :Third National Drainage Symposium Proceedings No. 77-1. Am.Soc. Agr. Engr., St. Joseph, MI. pp 91-98, 1976.

•Barber, S.A., Soil Nutrient Bioavailability, A Mechanistic Approach, John Wiley & Sons, New York, NY 1984.

•Blackmer, A.M., G.D. Binford and N.M.El-Hout, Effects of Rates of Nitrogen Fertilization on corn Yields, Nitrogen Losses from Soils and Energy Consumption, in Integrated Farm Management Demonstration Program, 1989 Progress Report, Iowa State University, 1989.

•Bowmer, K.H., Nutrient removal from Effluents by an Artificial Wetland Influence of Rhizosphere Aeration and Preferential Flow Studied Using Bromide and Dye Tracers, Water Research, Vol.21,No.5, pp. 591-599, 1981.

•Burwell, R.E., G.E. Schuman, H.G. Heinemann and R.G. Spomer, Nitrogen and Phosphorus Movement from Agricultural Watersheds, Journal of Soil and Water Conservation, Vol. 32, No.5, pp. 226-230, 1977.

•Christ,J.B., J.A. Mattson and S. Winaur, Effect of Severing and Stump Height on Coppice Growth, in Intensive Plantation Culture: 12 Years Research, Report NC-91, St.Paul, MN, pp. 58-64, 1983.

•Cooper,J.R., J.W. Gilliam and T.C.Jacobs, Riparian Areas as a Control of Non-point Pollutants, Watershed Research Perspectives, Smithsonian Institution Press, Washington, D.C., 1986.

•Council of Agricultural Science and Technology (CAST), Agriculture and Groundwater Quality, Report No. 103, Ames, Iowa, pp. 20, 1985.

•Crites, R.W. and S.C. Reed, Technology and Costs of Wastewater Application to Forest Systems, The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes, Univ. of Washington Press, Seattle, WA., pp. 349-355, 1986.

•Dickman, D.I. and Stuart,K.W., The Culture of Poplars in Eastern North America, Michigan State University Press, Lansing, MI., 1983.

•Dillaha, T.A., J.H. Sherrard and L. Dowan, Long-term Effectiveness of Vegetative Filter Strips, Water Environment and Technology, Vol. 1, No. 3, pp. 418-421, 1989.

•Ek, A.B., J.E. Lenarz and A. Dudek, Growth and Yield of Populus Coppice Stands Grown Under Intensive Culture, Intensive Plantation culture: 12 Years Research. Report NC-91, St.Paul, MN, pp. 64-72, 1983.

•Glass, A.D.M., Plant Nutrition, Jones and Bartlett Publishers, Boston MA., pp 40-55, 1989.

•Gregory, P.J., Root Development and Function, Society of Experimental Biology, 1987,

•Haynes, R.J., Mineral Nitrogen in the Plant-Soil System, Academic Press, Inc. New York, NY. pp 166-221, 1986.

•Isebrands, J.G.,et al, Yield Physiology of Short Rotation Intensively Cultured Poplars, in Intensive Plantation culture: 12 Years Research. Report NC-91, St.Paul, MN, pp. 77-94, 1983.

•Jacobs, T.C. and J.W. Gilliam, Riparian Losses of Nitrate-Nitrogen from Agricultural Drainage Waters, J.Environmental Quality, Vol. 14, pp. 472-478, 1985.

•Kawase, M.,Anatomical and Morphological Adaptation of Plants to Waterlogging, HortScience, Vol. 16, no. 1, pp 30-34, 1981.

•Kramer, L.A., R.L. Poggensee and M.I.Suckup, 1989 Deep Loess Research Station Progress Report, USDA-ARS Council Bluffs Station, Washington, D.C., 1989.

•Lewis, O.A.M., Plants and Nitrogen, Edward Arnold Publishers, London, England, pp. 1-48, 1986.

•Licht, L.A. , Deep-rooted Poplar Trees Grown in the Riparian Zone for Biomass Production and Non-point Source Pollution Control, Ph.D. Thesis, University of Iowa, Iowa City, IA., 1990.

•Lowrance,R., et al, Riparian Forests as Nutrient Filters in Agricultural Watersheds, Bioscience Vol. 34, pp. 374-377, 1984.

•Mitsch, W.J. and J.G. Gosselink, Wetlands, Van Nostrand Reinhold, New York, NY., pp. 330-344, 1986.

•National Research Council (NRC), Nitrates: an Environmental Assessment, National Academy of Sciences, Washington, D.C., 1978.

•Overcash M.R. and D.Pal, Design of Land Treatment Systems for Industrial Wastes-Theory and Practice, Ann Arbor Science, MI., pp 461-465, 1981.

•Schlosser, I.J. and J.R. Karr, Raparian Vegetation and Channel Morphology Impact on Spatial Patterns of Water Quality in Agricultural Watersheds. Environmental Management, Vol. 5, pp. 233-243, 1989.

•Tisdale, S.L. and W.L. Nelson, Soil Fertility and Fertilizers, 3rd Ed., Macmillan Publishing Co., Inc., New York, N.Y., pp 54-120, 1975.

•U.S.Department of Agriculture, SCS Technical Guide, Sec. 393, United States Dept. of Agriculture, Soil Conservation Service, Washington, D.C., pp. 1-5, 1988.

•U.S. EPA, Process Design Manual: Land Treatment of Municipal Wastewater, EPA G25/1-81-013, Washington, D.C., 1981.

•Urie, D.H., Opportunities for Forest Land Treatment of Domestic Wastewater in the Golden Sands Resource Conservation and Development Area.

Wisconsin, USDA Forest Service 43-63WA-7-57, Washington, D.C., pp. 12-40, 1987.

•Zavitkovshi,J., Projected and Actual Biomass Production of 2- and 10- year-old Intensively Grown Populus 'Tristis #1',in Intensive Plantation culture: 12 Years Research. Report NC-91, St.Paul, MN., pp. 12-17, 1983.