Best Management Practices
Poplar Manual
For Agroforestry Applications in Minnesota

September/2007

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Introduction

History

There has been a long history of poplar planting in Minnesota dating back to the early settlement of the state. Early pioneers planted trees for shelter around their homesteads established after the Homestead Law of 1862. Many windbreak and shelterbelt trees consisted of native eastern cottonwoods, and by 1900 they included poplar hybrids introduced from Europe. Some of the early research on shelterbelts was done in Minnesota in the 1930's and 1940's by J. Stoeckler of the Lakes States Forest Experiment Station in St. Paul. In the 1940's Scott Pauley of the Department of Forestry at University of Minnesota worked on poplar genetics and was instrumental in collecting seed of eastern cottonwood for international collaborators around the world. He was famous for his statement that - - "poplars…are truly the 'guinea pigs' of the forest tree breeding". In the 1950's Ernst Schreiner of the Northeastern Forest Experiment Station distributed poplar hybrids he produced in the Northeast to cooperating Minnesota farmers. At that time dozens of farmers planted Schreiner's "Northeast" hybrid poplars throughout the state. In the 1960's Carl Mohn moved from Mississippi to the University of Minnesota and began a poplar breeding program that produced valuable poplar clones for the region. In the late 1960's and early 1970's the US Department of Energy initiated a Short Rotation Woody Crops Program that provided funding for poplar research at the North Central Forest Experiment Station in St. Paul and their cooperators including the University of Minnesota (Ranney et al, 1987). That research continued until 2002 and included studies of poplar cultivation, genetics, tree selection methods, physiology and growth and yield. It included funds for a Regional Poplar Plantation Network (Hansen et al, 1994, Netzer et al, 2002) that was the basis for poplar clone recommendations in this manual.

In the 1990's there was a huge increase in poplar planting and research in Minnesota. The Aspen Genetics Cooperative moved to Grand Rapids and conducted numerous projects. Champion Paper Corporation began operations in the Alexandria area, planting thousands of acres of hybrid poplars for pulp and paper. In 2000 International Paper purchased Champion and more recently Verso Paper acquired more than 15,000 acres of the company and leased lands in the Alexandria area. In the early 1990's WesMin Resource, Conservation and Development worked with Minnesota Department of Natural Resources and Energy Performance Systems to investigate poplar planting potential for bioenergy. In 1995 the Oklee Tree Project was initiated as a cooperative effort between the Agricultural Utilization Research Institute (AURI) of the University of Minnesota – Crookston, the National Resources Research Institute (NRRI) in Duluth, and the Minnesota Power company. Nearly 3000 acres of hybrid poplars were planted by 1997 during that project. At about the same time the Minnesota Agro-Forestry Cooperative was formed to promote poplar planting on agricultural lands in western Minnesota. The Center for Integrated Natural Resource and Agricultural Management (CINRAM) was formed in 1995 at University of Minnesota to promote agroforestry including poplar planting. In 1996 the Minnesota Hybrid Poplar Research Cooperative (MHPRC) was formed with state funding to breed and test new poplar hybrids and evaluate them throughout Minnesota. In the 2000's activity has continued with the formation of the West Central Regional Sustainable Development Partnership involving 12 counties in west central Minnesota to help promote sustainability of natural resources, and agriculture in the region including poplar planting opportunities for farmers. Moreover, a bioenergy project known as the Laurentian Project affiliated with Xcel Energy is planting poplars in Northeastern Minnesota near Hibbing for whole tree wood burning for energy. These activities easily qualify Minnesota as one of the most active poplar planting states in the US.

Over the last 25 years there have been a number of publications on "How To" establish hybrid poplars (Hansen and Phipps, 1981; Zavitkovski and Strong, 1982; Hansen et al, 1983), guidelines for establishing poplar plantations in Minnesota (Rose, 1992; Hansen et al, 1993; AURI, 1993-1998), growers guide for hybrid poplar in Canada (Boysen and Strobl, 1991; PFRA, 2001, Oosten, 2006) and hybrid poplar crop guidelines (Demchik et al, 2002) and a hybrid poplar handbook (Minnesota DNR/Wes Min 2004). Each of these publications had value at the time and many still contain valuable information for establishing poplar plantations in Minnesota.

There is a need to update the present handbooks due to the increasing emphasis on environmental issues related to poplar planting in Minnesota. There is especially a need for a "Best Management Practices" (BMP's) manual for poplar planting for wellhead protection, riparian buffers, agroforestry, livestock feeding operations, bioenergy plantings, organic farming, and phytoremediation projects, all of which are presently increasing in Minnesota. "BMP's" are economically sound voluntary guidelines to help the agriculture and forest communities improve and protect water quality of the states' lakes, rivers, wetlands and wells. They are a result of the Federal Clean Water Act, and the 1987 Water Quality Act, which requires each state to develop procedures and programs to reduce non-point pollution. Another aspect to BMP's is called "Total Maximum Daily Loads" (TMDL's). The state is required to do a TMDL study of each pollutant that does not meet state water quality standards (Clean Water Act, Section 303). Unfortunately, in many cases nitrogen, phosphorous and certain pesticides exceed state standards in Minnesota wells, streams, and lakes. This BMP manual is aimed at minimizing the negative effects of poplar culture on water quality in Minnesota.

The manual includes new research information and recommendations pertaining to poplar culture in Minnesota, including new clone performance, herbicide use, water quality regulations, invasive plants, and wildlife habitat. It is intended for the use of any landowner interested in growing poplar from the small private landowner with a few acres to the industrial landowner with thousands of acres. The purpose of the manual is to inform landowners of practical and economic "BMP's" to minimize non-point pollution of soil and water during agroforestry applications in Minnesota.

<u>Terminology</u>

There are numerous technical terms used to describe BMP's for poplar culture. In a practical manual it is important that these terms are defined in order to assure clarity and accuracy of the practices. There are, of course, an exhaustive list of forestry and agronomic terms available - - many are beyond the scope of this manual (see SAF 1958). Here we define important terms related to poplar culture that are commonly misused, confusing, and/or misinterpreted by practitioners.

Agroforestry: An integrated land-use system that purposely combines trees with crops and/or livestock production to increase profitability, sustainability, environmental protection, and social acceptance. Examples of agroforestry include alleycropping, intercropping, and silvopasture.

Clone: Individuals reproduced asexually from a common mother plant either naturally or by human propagation; therefore genetically identical. For example, aspen clones naturally from sprouting from the roots of the mother plant. Some clones are manmade from cuttings or grafts.

Humans have cloned important plants for centuries and clones are not necessarily associated with biotechnology.

Confined Animal Feeding Operations (CAFO's): Livestock confinement operations having more than 1000 animal units.

Coppice: Sprout growth originating from the cut stem of a tree or root of a cut tree.

Cultivar: Abbreviation for cultivated variety. Plants with distinctive characteristics; usually given a specific English name. A cultivar can be a clone or a seedling. Similar to variety.

Genetically modified organism (GMO): A GMO is an organism that has had its genome or genetic code altered by human intervention. The genetic modification may be used to alter traits such as insect and disease resistance, herbicide tolerance, growth rate or chemical composition. GMO poplars are currently not being planted in Minnesota and GMO's are presently not an acceptable BMP for Forest Certification.

Hybrid: Hybrids are offspring of cross breeding of parents of different genetic makeup irrespective of taxonomy (SAF 1958). Hybrids can be within the same species, i.e. hybrid corn, or between two species.

Hybrid poplar: Hybrid poplars, therefore, are offspring from poplar trees of different genetic makeup irrespective of species or origin. A hybrid is designed by the times (x) symbol. For example, the hybrid between *P deltoides and P. nigra* is written as *P. deltoides x P. nigra.* The mother parent is always listed first – here *P. deltoides* was the female parent and *P. nigra* the male. The abbreviation for this hybrid is referred to as DN - - e.g. DN 34. In this case, the female is native cottonwood and the male is non-native black poplar from Europe.

Many agency professionals have a bias against planting hybrid poplars because they believe they are non-native and worry that they may hybridize with native trees. They are NOT correct. Some hybrids are non-native and introduced to the US, but many are NOT. There are hybrids of native trees such as aspen, eastern cottonwood, balsam poplar, or western black poplar. They are native hybrids and perfectly acceptable for planting in the Minnesota landscapes!!

Hybrid vigor: Increased vigor, growth, size, yield or function of a hybrid compared to its parents.

Invasive plant: Non-native plant usually from Europe or Asia that became established in a native plant community and/or wild area replacing native vegetation. It usually refers to plants that did not occur in an area before European settlement.

Noxious weeds – plants legally considered harmful to the public health environment, natural areas, crops and livestock (e.g. Canadian thistle)

Organic farming: A farm of sustainable agriculture generally carried out without the use of synthetic fertilizer, herbicides or pesticides. Organic practices include crop rotation, cover crops, green manure, livestock manure, composting and cultivation.

Poplar**:** Poplars are fast growing tree species that are a member of the willow family. There are only four poplar species native to Minnesota (Table 1), but all four are of economic, ecological, and environmental importance. Species names are designated with genus and species in Latin and are italicized. For example, *Populus deltoides* is eastern cottonwood. There are also some natural occurring and many man-made hybrids (see below) of poplar species planted in Minnesota including hybrids of poplars from other parts of North America, Asia and Europe. All these are sometimes referred to locally as "poplars".

Phytoremediation: The use of plants to clean up and/or remediate sites by removing contaminants from soil and water. Poplars, willows, and native grasses are the most important plants used for phytoremediation in Minnesota.

Riparian buffers: Streamside plantings of trees, shrubs, and grasses designed to intercept sediment, nutrients and/or contaminants from surface water runoff, wastewater or groundwater before they reach the stream.

Shelterbelt: Single or multiple rows of trees and/or shrubs planted for environmental purposes surrounding fields of agricultural crops.

Short rotation woody crop: Growing trees as a crop using agricultural practices on a rotation generally less than 15 years.

Variety: A subdivision of a species produced by selective breeding with distinctive characteristics and maintained by cultivation - - often given an English name to separate it from other plants. Variety is usually commercially propagated.

Vegetative filter: a tree, shrub, or grass planting designed to manage specific sources of nutrients, wastewater, landfill leachate, and/or biofuel ash. These plantings are not usually associated with a lake, river, stream, or wetland.

Windbreak: Single or multiple rows of trees and/or shrubs established for environmental purposes around farmsteads.

Advanced Planning

Careful advanced planning is needed to have a successful poplar planting. Many failures are due to the lack of advanced planning or a hurried effort to get plantings into the ground. The first step of planning is to define the objective of the planting. The objectives of poplar plantings in Minnesota can be one or more of many options and benefits. They include alternative sources of income such as wood production, bioenergy, environmental benefits such as soil conservation and water quality enhancement, agroforestry that often combines economic and environmental objectives, wildlife benefits, conservation easements in perpetuity, livestock waste and odor management and/or aesthetics for improving land value. It is possible to have multi- benefits from poplar plantings if properly planned and designed.

The next step to advanced planning is identifying suitable sites and collecting data about them. This data includes soil series, soil quality and pH which is usually available from the local Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). Soil surveys are often useful to refine and augment the soil information on a tract. In Minnesota soil pH and drainage along with flood history is necessary. This information is needed to make a site selection.

The next step is to consult the “best management practices’ guide to assist in advanced planning. Site preparation is almost always needed in the year prior to planting, and poplar clone ordering and procurement can sometimes take more than one year if the clones of choice are not available. In all cases poplar clones must be ordered from a nursery in the autumn prior to the planting year to insure availability.

The last step is for the landowner to contact state and federal government agencies to obtain permits for projects associated with wetlands, wellhead protection areas, or livestock operations. Information on permits is available from the Minnesota Pollution Control Agency, and/or the Minnesota Department of Agriculture (see websites or contact information below).

Contact Information:

1) Minnesota Pollution Control Agency, Confined Feedlot Operations, Dave Wall, Tele: 651-296-8440,
   Email: David.Wall@state.mn.us
   Website: www.pca.state.mn.us
2) Minnesota Department of Agriculture, Bruce Montgomery, 90 W. Plato Blvd, St. Paul, MN 55107-2094, Tele: 651-297-7178,
   Email: bruce.montgomery@state.mn.us,
   Website: www.mda.state.mn.us

There are also a number of landowner assistance programs available for tree planting through federal and state agencies. Some of these programs are cost shared by the agencies.

US Department of Agriculture (USDA)

There are many USDA landowner assistance programs for tree planting in Minnesota. These programs are aimed at removing environmentally sensitive farmland from production to improve water quality of lakes, streams, and rivers, protect groundwater and improve wildlife habitat. The programs are largely cost-shares and/or easements administered by the USDA Farm Service Agency in cooperation with the Natural Resource Conservation Service, Cooperative State Extension, Minnesota Department of Natural Resource foresters and local soil and water conservation districts. The Resource Conservation and Development (RC&D) councils throughout the state are also contacts for the USDA programs.

Conservation Reserve Program (CRP):

The CRP is a voluntary program that offers annual rental payments and cost share assistance to establish long term resource conserving covers on eligible land (i.e. with history of crop production). Landowners sign contracts for 10 to 15 years and there is a continuous sign up period. Harvesting is not permitted during the contract, but is permitted after the contracts expire. There are a number of eligible conservation practices (CP) that include tree planting. They include the following practices and CP numbers:

General Sign-up CRP Practices

- Tree planting (CP3)
- Hardwood tree planting (CP3A)
- Permanent wildlife habitat (CP3B & 4D)

Continuous Sign-up CRP Practices

- Field windbreaks (CP5A)
- Shelterbelts (CP16A)
- Living snow fences (CP17A)
- Riparian buffers (CP22)
- Rare and declining habitat (CP25)
- Farmable wetlands pilot wetland and buffer (CP27/CP28)
- Marginal pastureland wetland buffer (CP30)
- Bottomland timber establishment on wetlands (CP31)
- Habitat buffers for upland birds (CP33)
  (Only for selected SE, MN Counties)

Land is also eligible within an Environmental Protection Agency designated wellhead protection area. Landowners work with agency staff to develop a conservation plan that includes one or more of the above CP's on their land.

Conservation Reserve Enhancement Program (CREP):

The CREP program is a program that combines the USDA CRP program with Minnesota's Reinvest in Minnesota (RIM) reserve program to retire farmland in Minnesota. The program is targeted toward frequently flooded cropland, riparian buffers along cropland, and wetlands with potential for improving water quality and wildlife benefits. Landowners work with staff to produce a conservation plan that is screened by an agency committee to determine eligibility. Some of the contracts are permanent easements and the remaining are for 45 years.

Environmental Quality Incentives Program (EQIP):

EQIP is a voluntary conservation program administered by the USDA NRCS. Landowners through EQIP receive financial and technical assistance for conservation practices on agricultural land. Some of the eligible conservation practices related to tree planting are:

- Livestock wastewater control systems
- Feedlot runoff control systems
- Tree plantings
- Streambank stabilization

EQIP may pay landowners up to 50% of the costs of eligible practices. It also may pay incentive payments to landowners to adopt eligible land management practices such as manure management, nutrient management and wildlife habitat management. Applications are accepted locally and ranked locally.

Conservation Security Program (CSP):

CSP is a voluntary program on eligible watersheds offering payments to landowners for eligible conservation and environmental programs. Payments are based upon the quality of conservation. It is available on only selected watersheds in Minnesota and is somewhat limited. It is only available to landowners with documented conservation practices on their land.

Minnesota Board of Water and Soil Resources (BWSR)

BWSR offers landowners in Minnesota conservation easement payments for ending cropping and/or grazing on the land while initiating conservation practices such as establishing vegetative cover and restoring drained wetlands. The two programs are Permanent Wetland Preserves Program (PWP) and Reinvest in Minnesota (RIM) Reserve Program. They are administered by the Minnesota BWSR at the state level, and by soil and water conservation districts at the local level. Payments vary by area and cropping history. Most easements are for perpetuity but some are for limited duration easements not less than 20 years. The landowner is responsible for maintenance of the practices and controlling noxious weeds.

There may be some limited low interest loan programs available from soil and water conservation districts for low-cost financing of conservation projects such as water quality projects that control sediment and nutrient runoff.

Non-Governmental Programs

Minnesota Pheasants Forever (PF):

The Minnesota chapter of PF cost shares projects with landowners that establish vegetation for enhancing wildlife habitat in Minnesota. Emphasis is on establishing food plots, nesting cover and woody cover for winter survival. These projects include tree planting in riparian buffers, and shelterbelts.

Contact Information:

1) Website: www.minnesotapf.org/contact.cfm
   Matt Holland, Director
   679 W. River Road
   New London, MN 56273
   Tele: 320-354-4377
   Email: ringneck@tds.net

2) Dennis Pederson, PF Habitat Projects
   3274 490th St.
   Montevideo, MN 56265
   Tele: 320-564-0100
   Email: depederson@mvtwireless.com

Minnesota Agro-Forestry (MAFC):

The MAFC is a cooperative established to raise and market short rotation woody crops and other agricultural products for profit, while providing economic, environmental, and civic opportunities for the coop members and communities. Qualified landowners will receive advanced payments to establish and grow short rotation woody corps in Minnesota. At harvest, the advanced loans would be repaid to the cooperative.

Contact Information:

Dennis Gibson
MN Agroforestry Cooperative
2030 – 10th Ave. NE
Montevideo, MN 56265
Tele: 320-269-8103
Email: dgibson@gibsontransfer.com

Site Selection and Suitability

There are many factors to consider when selecting a suitable site for poplar planting in Minnesota. They include soil factors, location, as well as operational factors. Poplars grow "best" on well-drained fertile, agricultural soils where there is adequate annual rainfall or irrigation available, and a frost-free growing season of over 150 days. Unfortunately, land values in Minnesota often make this land uneconomical for growing poplars. The soil surveys done during the advanced planning period are useful in site selection. It is important to use the "best" available sites for poplar growing and avoid planting poplars on "poor" sites. The following soil properties are most important for poplar growing:

- Soil type and texture
- Soil moisture and drainage
- Soil aeration and depth
- Soil pH
- Soil fertility

Poplars grow "best" on deep sandy loams to clay loams. Poplars do not grow well if there is hardpan in the root zone. They perform "best" where soils are moist throughout the growing season, and where there is high moisture holding capacity coupled with adequate drainage. Excessively drained soils are not good for poplar growing. However, most poplars do not do well in water logged or saline soils especially during the growing season. Some flooding can be tolerated during the dormant season.

The choice of clone and "BMP's" vary depending upon whether the site to be planted is an upland or a riparian site. In Minnesota the soils are very heterogeneous. There is a very wide range of soils from excessively drained to water logged. It is important to choose sites that have less than 8% slope. In Minnesota the soil pH should be between 5.0 and 7.5. Acid soils below pH 5.0 and soils with pH above 8 are not good for growing poplars. The trees are not able to take up nutrients under these conditions. In southwestern Minnesota in Swift and Chippewa counties there are many soils where the pH is over 8 and the drainage is poor. These soils are not suited to grow most poplar clones. Poplars grow "best" where the soil organic matter is from 3 to 8% and where adequate nitrogen is available. Moderate to high levels of phosphorous and potassium are also needed. The "best" soils in Minnesota are the loams and sandy loams – examples of these soils are Arvilla sandy loam, Waukon loam, LeSuer loam, and Cokato loam.

The location of the site is important. Access is important for cultural practices and harvest, and it should be located near the markets or transportation to markets. These factors have become more important with recent increases in the cost of transportation fuels. They should not be planted in areas designated as environmentally sensitive areas. The plantings should not be under overhead power lines or over underground utilities. Also, plantings should not be within 50 feet of tile lines. The size and shape of the planting should be compatible with equipment and adjacent parcels. Long rectangular fields are more energy (and cost) efficient to manage.

Site selection for environmental plantings and phytoremediation vary with each project. The planting site is usually dictated by the location of the livestock confinement building or the feedlot, or by the location of the wellhead. Riparian plantings are usually sited along the course of streams or rivers, although vegetation strips can be sited along the contour of a field to take the place of a terrace.

Phytoremediation plantings are sited either directly upon the contaminated soils or groundwater, or between the source of contamination and a waterway or stream. Some plantings are located in blocks near the contaminated soil or water for easy spreading or irrigation. Windbreaks are sited to protect buildings from the prevailing winds and shelterbelts and timberbelts are sited on the periphery of fields between adjacent crops.

Consideration must be given to plant hardiness zones in Minnesota when selecting clones (see below) and sites for poplar planting.

Planting Design

<u>Windbreaks/Shelterbelts/Living Snow Fences/Timberbelts</u>

Windbreaks and shelterbelts have been planted in Minnesota since early settlement. Living snow fences and timberbelts are relatively new concepts. The designs of windbreaks and shelterbelts have been discussed, debated and revised since the1930's. Farmstead windbreaks should have multiple rows of trees and shrubs to provide wind, temperature, snow, and sound protection for home, farm buildings, feedlots, and livestock enclosures. The windbreak should have at least three rows - - one or more on the windward side, one or more interior rows, and one or more on the leeward side. Four to six rows are "best", but even one or two rows are beneficial. Windbreaks in Minnesota should be L-shaped on the north and west sides of the farmstead. Windbreaks should be at least 65 feet from the buildings and the rows should be from 10 to 15 feet apart. Many different configurations have been used in Minnesota. The windward row or rows should be hybrid poplars or cottonwoods planted at 8 foot spacing in the row. If more than one row is planted, offset the trees in adjacent rows for additional protection. The interior row or rows should be evergreen conifers such as white spruce, Black Hills spruce (in western Minnesota) or Norway spruce for winter protection. These rows could also include a long lived hardwood such as bur or red oak. They should be planted at 8 foot spacing within the row and offset from the adjacent row. Previously, green ash was also a recommended interior species, but it is vulnerable to an exotic insect and is no longer recommended. The leeward row or rows should be a shrub planted at 4 foot spacing within the row.

The following shrubs are recommended: common lilac, red osier dogwood, ninebark, highbush cranberry (V*iburnum)*, or wild plum. *Caragana* and honeysuckle are no longer recommended because they are invasive plants. Common lilac should be planted alone in a row, while other shrubs can be mixed. These shrubs provide excellent wildlife habitat as well as wind and snow protection.

Shelterbelts are one or more rows of trees (and sometimes shrubs) designed to prevent soil erosion, provide wind protection, and snow management for fields and crops. The concept is similar to windbreaks described above, except that usually space is limited around fields so the number of rows available is often limited to one to three rows. Living snow fences are similar and planted to protect roads and drainage ditches. A single row of hybrid poplar or cottonwood provides some rapid early wind protection but multiple rows that include conifers provide longer term and winter protection once they are established. Again, white spruce, Norway spruce or Black Hills spruce in the north and west of Minnesota are the conifers of choice. If space allows, an interior row of shrubs would be beneficial for wind and snow protection and snow management. Shelterbelts (even one row) provide wind protection for up to 10x the tree height. Shelterbelts can be established on any or all sides of the field, although the prevailing winds in Minnesota are from the north and west. A shrub row on the windward or leeward side of a shelterbelt also provides good snow catchment and wildlife protection, if possible. Shelterbelt trees should be planted in rows from 10 to 20 feet apart and 8 feet apart within the rows. Trees in adjacent rows should be offset. Shrubs, if used, should be 4 feet apart.

Timberbelts are similar to shelterbelts. They are multiple row shelterbelts planted with hybrid poplars or cottonwoods to provide protection for crops and soil from the wind, while at the same time producing salable wood products after the woody crop rotation age is reached (10 to 20 years in Minnesota). Many of the marketable wood products (see below) could be harvested from a timberbelt, and in the future carbon credit opportunities may be available. Timberbelt trees should be planted in rows from 10 to 15 feet apart, and on 8 foot centers within the rows. Trees in adjacent rows should be offset as in shelterbelts. Ten to 15 rows of trees could be planted in a timberbelt. Such plantings also provide beneficial corridors for wildlife between fields.

For windbreaks, shelterbelts, and timberbelts there are several choices of planting stock including bareroot stock, containerized stock, potted stock, or balled and burlap (B&B) stock (see section below). Multiple clones of poplars are recommended to provide diversity in the plantings.

Animal Confinements

Plantings around animal confinements are conceptually similar to windbreaks except that their purposes include odor management, dust management, and visual screens or barriers as well as wind and temperature protection. Planting around confinements should be a mixed hardwood and conifer design. Odors from animals are largely ammonia and methane and are short lived. They are "best" absorbed by hardwood tree leaves during the growing season. The heavier dust particles are "best" absorbed by evergreen conifer needles throughout the entire year. Around confinements fast growing hardwood species such as poplars and willows are used to provide an early nurse crop for evergreen conifers, and a fast visual screen. Shrubs are used to provide a continuous hedge-like screen for trapping odor and dust. The shrubs after 3 to 5 years also provide a visual screen between public roads and confinement operations.

The same species and clones recommended for windbreaks are useful for animal confinements with the addition of fast growing hybrid willows. One or more rows of hardwood trees such as poplar or willows are planted next to the confinement leaving a maintenance corridor. Trees are planted on 6 foot centers and rows should be from 8 to 10 feet apart. Evergreen conifers should be planted in the interior rows on 6 foot centers, but offset from adjacent rows. The outer exterior row should be a shrub row planted on 6 foot centers. Common lilac is usually the shrub of choice in these plantings as it grows rapidly and forms a continuous hedge-like screen after 3 to 5 years. Some landowners even add an additional outside row of fast growing poplars or willows for additional visual screening. For animal confinements bareroot stock, or containerized stock are the planting stock choices to maximize early tree and shrub growth.

Livestock Waste Disposal

Poplar plantings can be designed to facilitate livestock waste disposal. Both liquid and solid wastes contain high levels of organic matter, nitrogen ammonium N, organic nitrogen, phosphorous, and potassium. All are plant fertilizers that will enhance poplar tree growth. If properly distributed, manure can decrease reliance on commercial fertilizers and ground water can be protected from runoff. Tree planting can decrease odor if properly designed. Shelterbelts can be designed as above to protect groundwater adjacent to fields receiving liquid and/or solid manure. Again, fast growing poplars on the windward side with interior rows of evergreen conifers planted offset can decrease particulate and odor drift. The downwind side of the field should be planted at dense spacing such as 6 feet centers to capture particulates and cause wind plume dissipation.

Liquid manure can be used to irrigate block plantings of poplars that are designed as vegetative filters. Rows of poplar trees planted 10 to 20 feet apart can serve as a wastewater disposal site from animal confinement lagoons. Drip or sprinkler irrigation delivery systems can be used to distribute wastewater from confinement areas to the trees if in close proximity. Guidelines for crop water use and irrigation requirements are available from the NCRS. Liquid effluent from lagoons can be hauled to planting for spreading. Trees are planted in double rows on 8 to 10 foot centers so liquid can be spread from both sides. In Minnesota permits are needed for application of animal wastes on land and there are restrictions on the amount and time of year for application. Information is available from the Minnesota Department of Agriculture (www.mda.state.mn.us) and Minnesota Pollution Control Agency (www.pca.state.mn.us).

Riparian Buffers

Properly designed tree-based riparian buffers can help the landowner as follows:

- control soil erosion
- enhance and protect water quality
- stabilize eroding streambanks
- decrease flooding
- enhance fish and wildlife habitat
- provide marketable products
- improve visual aesthetics
- sequester carbon
- enhance recreation

A number of riparian buffer designs have been proposed. The currently accepted design is a 3-zone multi-species riparian buffer that includes a zone of unmanaged trees and shrubs near the stream, followed by a zone of managed trees and shrubs , and ending with native grasses adjacent to the agricultural crop (Schultz et al 2004). Any number of combinations of trees, shrubs and grasses are acceptable depending upon landowner objectives. Zone 1, the unmanaged zone near the stream should include native trees and shrubs such as cottonwoods and willows to stabilize the streambank, enhance organic matter, add vertical structure for wildlife habitat, and to trap flood debris. Zone 2, the managed zone should include block plantings of trees that will stabilize the soil, enhance soil quality and organic matter, add vertical structure for wildlife, shade the stream, provide organic matter and woody debris to the steam channel, and provide a variety of marketable wood products. This zone could include any of the following tree species: silver maple, hybrid poplars, cottonwood, swamp white oak and black walnut. Zone 2 can also include a mixture of shrubs such as red-osier dogwood, chokecherry, ninebark, *Viburnum*, and wild plum. Zone 3 is the zone adjacent to the cropland. It should include a mixture of native prairie grasses such as switchgrass, big bluestem, little bluestem, and Indiangrass. This zone slows the water entering the buffer, traps sediments and chemicals, adds organic matter to the soil, provides wildlife habitat; and provides forage crops.

Buffers can also be established between livestock feedlots and streams to intercept feedlot runoff that is high in sediments, nitrogen, phosphorous and pathogens before they reach the stream. Such buffers can be composed of trees, shrubs, and grasses similar to those described for riparian buffers. Riparian buffers can be various widths and must be at least 67 feet from the streambank. It is common to have multi-species buffers of 120, 160 to 180 feet along the stream. Tree spacings in a riparian buffer are usually 12 feet between rows and 6 feet within the row. This spacing results in about 600 trees per acres. Shrub spacing can be closer within the row.

<u>Block plantings</u>

Block plantings are usually planted for traditional wood products. There is no ideal tree spacing and it depends upon landowner objectives. The recommended spacing varies with poplar species and the desired product size (i.e. pulpwood, sawlogs, or veneer). Choice of spacing can also be dependent upon the landowners' operational and economic limitations such as equipment size and type. Poplars require full sun to achieve maximum productivity. Over the years the spacing recommendations for poplar planting for pulpwood in Minnesota has increased. The proposed rotation length has also increased as it also is dependent upon spacing. This increase is largely due to market demand and economic factors such as increased transportation costs. Formerly, recommended tree spacings were 8 x 8 feet, or 10 x 8 feet, or 10 x 10 feet, which equals 700, 550, to 400 trees per acre. However, 8 foot spacing between rows was somewhat restrictive for tending with modern farm equipment. After the 1st year it required either hand weeding, narrow gauge orchard tractors, or ATV equipment. Research over the years has shown that the volume produced by wider spacings on a 10 to 12 year rotation is equal to that of close spacing and it is concentrated on larger piece sizes that are easier and more efficient to harvest, store, and transport. Closer spacings are still recommended for non-traditional products that tolerate smaller piece size such as bioenergy and mulch. The close spacings may also be used by organic farmers who are using hand or horse labor to produce a firewood crop. Thus, spacing must be selected based upon utilization goal.

The current recommended spacing for traditional wood products in Minnesota is 12 x 8 foot or 12 x 12 foot spacing, which equals 450 or 300 trees per acre, respectively. This spacing is 12 feet between rows and either 8 or 12 feet between trees within the rows, and is suited to clones with medium to wide spread crowns and is amenable to use of modern farm equipment for tending. Another option available is to plant at closer spacing such as 12 x 6 foot or 10 x 6 foot spacing followed by a thinning at mid-rotation (i.e. after 5 to 6 years). The recommended initial spacing and planting density is usually the one suited to the desired end product at harvest.

Several poplar clones should be planted on a site to maintain genetic diversity and decrease pest and disease attack. Planting multiple clones also provides protection against clone-related damage such as wind that might occur some time during the rotation. Blocks can be planted with multiple clones in rows or mixtures. But, this practice is not recommended because the planting production is usually compromised by between-clone competition.

The "BMP" in Minnesota is to plant small mosaics of multiple, isolated, but connected "pure" blocks of 3 or more poplar clones on the landscape. Small is defined as 20 to 40 acres for each clone. This practice will insure maximum production, genetic diversity, minimize pest attacks, and provide wildlife habitat and corridors.

Biomass and bioenergy plantings

Poplar plantings for biomass and bioenergy can be planted at closer spacings, and on shorter rotations. These plantings are currently more economically viable in Minnesota with rising fuel prices and expanding non-traditional markets. The earlier guidelines for achieving maximum biomass production on a site on short rotations ranged from 3 x 3 to 6 x 6 foot spacing. Close spacings capitalize on deploying the maximum number of trees per acre from the beginning of the planting. A 4 x 4 foot spacing or 2700 trees per acre produces trees that are 4 to 6 inches in diameter in 6 to 8 years. Some plantings in Minnesota are at a 5 x 5 foot spacing, however. Biomass yields of 5 to 6 tons per acre per year can be expected in Minnesota on sites with good moisture and nutrients. These figures include branches, bark and small diameter wood (not leaves) that are usable for bioenergy or mulch, but not traditional wood products. Leaves comprise about 10% of the total biomass and are typically left on site to build organic matter and nutrients of the soil. Organic farmers may wish to harvest the foliage for animal feeding. Poplar leaves are high in nitrogen and protein and are good animal feedstocks.

When the landowner objective is to produce bioenergy or mulch, coppicing may be a viable option for the second rotation. Coppicing during the dormant season gives "best" results. Coppicing results in multiple stems per stump and there is an immediate increase in stem size and vigor and resultant production in the first years after cutting. Multiple stems complicate tending and biomass harvesting of the small diameter stems and branches. Coppice stands also tend to be more susceptible to pests and diseases than first rotation stands.

Wellhead designs

Wellhead designs are intended to protect groundwater in the vicinity of public wells. The goal of wellhead designs of poplar plantings are to:

- decrease nitrogen, phosphorous, and pesticides in the groundwater, and in farm and rural municipality water supplies
- decrease soil erosion locally
- decrease runoff to streams that will affect the Mississippi River watershed and indirectly affect the Gulf of Mexico
- diversify the agricultural landscape thereby increasing wildlife habitat
- enhance recreation
- provide alternative income from the sale of wood products to farmers

Wellhead designs of poplar plantings depend heavily on specific sites such as well location, groundwater flow direction, and agricultural practices. Agricultural practices such as irrigation and livestock feedlots and/or confinements are important factors to consider. In areas where irrigation is not used and where livestock operations are minimal, landowners in wellhead protection areas should adopt as many of the tree, shrub and grass based conservation buffers as they can. These include the above mentioned 3-zone riparian buffers, shelterbelts, living snow fences and timberbelts. Other helpful conservation practices could include grass and shrub based contour strips, vegetative barriers, field borders, and alley crops in the wellhead protection area (USDA, 1997).

When irrigation and/or livestock operations are located in the wellhead protection areas, the above conservation practices also are helpful, but additional measures and design factors are needed to protect water quality. Excess irrigation water applied to crops contain high levels of nitrogen, phosphorous, potassium and pesticides. These compounds, unless treated, eventually reach the ground water. Trees can be planted to intercept drainage water by planting then down gradient between the source and the well, or the water can be diverted and stored in lagoons or ponds and then applied to poplar plantings with a spray emitter or drip irrigation systems. The poplars take up large quantities of water and recycle it, while using excess nutrients and breaking down pesticides. Trees can be established in blocks for this specific purpose or can be established in center pivot corners. Other options include pumping high nitrogen groundwater from existing down gradient wells back up gradient to irrigate poplar blocks. This approach recycles the high nutrient and pesticide groundwater back to plantings before it reaches the water wells. Another option is to run offshoot lines or drip irrigation lines from existing overhead irrigation systems to poplar plantings.

When there are livestock operations in the wellhead, runoff from feedlots or confinements add to the nitrogen rich groundwater. As mentioned above, solid and liquid waste from these operations can be stored in lagoons or composted and then spread on poplar plantings in the wellhead protection zone to decrease runoff and percolation into the groundwater. In all cases, maximum loading of nutrients must be monitored and some winter applications are not permissible.

<u>Other agroforestry practices</u>

There are increasing opportunities for intercropping or alley cropping of poplar with agronomic and horticultural crops, and for silvopastoral systems in Minnesota. Agricultural crops such as barley, clover, oats, rye, wheat, corn, sorghum, soybeans, field beans, peas, melons, fruit trees and potatoes can be intercropped with poplars. The production of the companion crops is "best" in the first 3 years of poplar production for trees planted at conventional spacings while the poplar trees are getting established. After that period poplar crown closure limits the light, water and nutrients available for the companion crop. Annual rye and oats intercropped with poplar serve a dual purpose in that they have reasonable yields while at the same time controlling weeds and building organic matter as a green manure crop.

There is also the possibility of growing trees at very wide spacings such as 50 feet or more, and growing the above agricultural and horticultural crops described above within them. This approach is similar to the shelterbelt concepts previously described and are limited o the early years of the poplar planting. After that, the companion crop yields decline due to a zone of competition between the poplars and the crops. In locations where winds are severe the intercropped crops can actually benefit in yields from the shelter provided by the poplars. It is important that cropping practices such as irrigation and pesticide use be compatible as poplars are sensitive to many herbicides used in agriculture. However, there are some promising intercropping opportunities for organic farmers with poplars.

There are also opportunities when poplars are grown at wide spacing and on long rotations for silvopastoral operations. These practices are common with poplars in Italy and New Zealand. Poplars must be protected from livestock in the first 5 years or more of the rotation. Silvopastures provide mutual benefits for poplars and animals. The animals are benefited by the shelter provided by the poplars during the summer and the winter, and the trees are benefited by the weed control provided by controlled and managed animal grazing that minimizes compaction and nutrients from their manure.

Phytoremediation

There are many emerging phytoremediation opportunities using poplars (and willows) in Minnesota. Phytoremediation systems are designed to capture, remove, or remediate air, soil, and/or water contaminants from the environment. Phytoremediation differs from standard conservation practices because of the value placed on the specific removal of the contaminant. Riparian buffers and vegetation filters are in a sense performing phytoremediation. Most phytoremediation applications use human-installed riparian buffers, vegetation filters or directed tree plantings to accomplish specific clean-up goals. An important principle of phytoremediation is to match the proper poplar (or willow) species or clone to the contaminated site. Poplars are often chosen as a phytoremediation tree species because they grow rapidly, have many and deep roots, and they take up large quantities of water. The roots not only take up large quantities of water, but also provide the root surface area where beneficial microbes and fungi that break down contaminants live. Poplars are used to take up a variety of contaminants including excess fertilizers, metals, petroleum products and pesticides (Licht and Isebrands, 2005).

Potential phytoremediation applications using poplars in Minnesota include:

1) buffers between:
    - leaking landfills and wetlands or streams
    - animal feedlots or confinements and streams
    - irrigation systems and drinking water wells
    - pesticide spills and wells

2) vegetation filters for:
    - disposing of municipal wastewater and biosolids (USDA Forest Service 2000)
    - disposing of solid and liquid animal wastes

3) directed plantings on:
    - pesticide spills
    - petrochemical spills

Phytoremediation plantings are designed to achieve maximum growth resulting in maximum water and contaminant uptake on the site. In many cases the landowner will want to harvest and utilize the resulting biomass from phytoremediation plantings. The biomass from plantings below animal feedlots, irrigations systems, municipal wastewater, and biosolids or on petrochemical can be used for bioenergy, mulch or reconstituted wood products without concern. The biomass from landfills and pesticide spills may not be utilized unless it has contaminant levels below regulatory guidelines. The typical tree spacing in phytoremediation planting is closer than in other operational plantings. Desirable tree spacing for phytoremediation often is 10 x 6 foot spacing, or 725 trees per acre. Fast growing clones are preferred in order to maximize growth. Native trees are preferred in riparian zones and wetlands, but in some cases, non-native trees are used to maximize contaminant uptake in a municipal zone or livestock operation. Sometimes, coppicing during the dormant season is used after the first one or two years to enhance growth rate and vigor.

Site Preparation

Site preparation for poplar plantings in Minnesota varies greatly with site and location. It is not advisable to convert existing woodlots to poplar; woodlots offer the owner other options. Typically poplars are planted on upland abandoned lands or previously cropped land, or more recently in riparian lowlands. The site preparation methods vary greatly with site. Competition control is essential for establishing poplars on any site; no-till is not a good option for poplar plantings except when soil temperatures are high and soils have been under no-till for years. No-till is also preferred in certain phytoremediation applications when augering is used.

<u>Year One</u>

In all cases the selected site should be mowed or rotary cut in the year before planting and then sprayed with Roundup (or equivalent) on upland sites, or Rodeo or equivalent on riparian sites.

In previous poplar establishment guidelines plowing and disking followed by fallowing were standard recommendations. But, deep plowing exposes problematic dormant weed seed and releases stored soil organic carbon to the atmosphere. Thus, plowing should be avoided except in cases where thick sod is being converted. On upland sites where there is a hardpan or plow layer, chisel plowing or deep tillage to 1 foot depth should be used to break up the hardpan to improve soil aeration and tree root penetration. Aeration is critical for poplar growth. When the sites are small (less than 2 acres) augering through the plow layer with a tractor mounted or hand held auger may be a good alternative especially around livestock confinements and contaminated soils where phytoremediation is the goal.

On both upland and riparian sites disking after glyphosate application is recommended. On former agricultural land seeding a cover crop such as oats or annual rye in the fall before planting is a recommended BMP if winter erosion is possible. With riparian sites mowing strips or large individual circles followed by glyphosate applications is recommended. Glyphosate applications are part of BMP’s as glyphosate is short lived, green plant specific and biologically safe. Other herbicides should be minimized as part of BMP’s especially in riparian zones. In fact, landowners that are seeking Forest Stewardship Certification (FSC) are restricting their herbicide use to glyphosate and eliminating all other herbicide uses especially during site preparation.

<u>Year Two – Year of Planting</u>

In the spring of year two, the year of planting, an additional mowing, disking or field cultivation may be needed especially where tough weeds such as reed canary grass are present. Another glyphosate application may also be needed prior to planting. Mulching to control weeds during the year of planting is also effective especially on smaller tracts. Sawdust, wood chips, and bark are good natural mulches. Straw is not recommended as it harbors rodents that damage young trees.

Plant Material Selection-Species and Clones

Introduction and Caution

A key to success of a poplar planting is matching the proper species and clone to the site. This choice is a difficult task in Minnesota because of the heterogeneous soils and varying microclimate from south to north and from east to west in the state. Consideration must be given to soil type, soil pH, water availability and drainage, microclimate, region of the state, pests and diseases, and availability of suitable poplar clonal material. Many of the plantation failures in the state are due to planting improper clones for the site.

Poplar clones

When one contemplates the choice of poplar clone for planting in Minnesota, it is frustrating to realize how few poplar clones are being recommended and are widely available. There are just four clones that are most widely recommended and available, DN-17 (Robusta), DN-34 (Eugenei), DN-182 (Raverdeau) and NM-6. All of these clones were produced in Europe in the 1890's, and introduced to Minnesota over one hundred years ago! Few other newer clones are available in quantity and no other ones are being planted at operational scales. Of the four above clones, only DN-34 and NM-6 survive over an entire 12 year rotation throughout Minnesota because of the presence of a stem forming canker disease known as *Septoria* canker, although *Septoria* has recently been identified in NM 6 plantings throughout the Midwest..

The other two clones, DN-17 and DN-182 and many others such as Siouxland are not resistant to *Septoria* canker and should not be planted in block plantations in Minnesota. There have been some successes with windbreak and shelterbelt plantations of these clones, but plantations of *Septoria* damaged trees can be found throughout Minnesota including the Moorhead, Alexandria, Perham and St. Paul areas.

Another important consideration to make on choice of poplar clone is whether the site to be planted is an upland or riparian site. Many of the hybrid poplar clones do not perform as well in periodically flooded soils. Native eastern cottonwood and cottonwood hybrids perform better on these soils, as well as certain hybrid poplars that have been tested in riparian zones.

According to the US Department of Agriculture Plant Hardiness zone map there are 5 plant hardiness zones in Minnesota – 2b, 3a, 3b, 4a, and 4b. Consideration must be given to these hardiness zones when choosing a poplar clone. For example, clones suitable for the far northern Minnesota will not perform the same as clones suitable for planting along the Iowa border in the southwest. For some northern sites aspen and balsam poplars may be a good choice while eastern cottonwood clones and hybrids will do well in the south.

Hansen et al (1994) made mid-rotation clonal recommendations for the Midwestern US. They recommended nine poplar clones that included the four previously mentioned clones, and 5 new hybrid clones including DN 2, DN 5, DN 70, NE 222 and I 45/51. These 5 new clones continue to show promise in Minnesota. In 2002 we evaluated the growth, yield and disease resistance of 7 to 12 year old poplar clones throughout Minnesota (Netzer et al, 2002). New clones were identified that were not previously recommended that consistently ranked high in Minnesota and were in many cases "better" than previously recommended clones (Table 2). They include the following poplar hybrids: DN 154, DN 164, DN 170, DN 177, NE 264, and NM-2. Unfortunately, *Septoria* canker disease can change over time and gradually infect previously resistant clones (Ostry and McNabb, 1986, Hansen et al, 1994). So, new poplar clones must always be under test and development for Minnesota.

It is also important to maintain diversity of poplar clones on the site. Planting mosaics of two or three poplar clone blocks with corridors between them will provide better wildlife habitat and decrease the plantation susceptibility to insect pests and diseases, and wind damage.

Another problem in clonal selection is that not all nurseries are selling "properly named" poplar clones that have been tested in the area and that are pest and disease resistant. Often the cheapest and most advertised clones are not the "best", so **buyer beware**. (Dickmann and Isebrands, 1999)

Recommendations:

1) Match the proper poplar clones to the site. Choose two or three poplar clones from the recommended clone list in Table 2.
2) Choose only clones tested in the region of the state that trees are to be planted.
3) Purchase stock from a responsible nursery – the cheapest is not usually the "best".

<u>Willows and prairie plants</u>

Willows, shrubs, prairie grasses and wildflowers are often used in multi-species riparian buffers with poplars and other long lived tree species. (Schultz et al, 2004) This buffer design has been very effective in improving water quality and wildlife habitat in the Midwest. Native willows are preferred in the streambank stabilization zone of the multi-species buffer. There are a number of native willow species in Minnesota: The preferred willow species for planting along streambanks are given in Table 3. They are available from several of the nurseries listed below. Native prairie grasses and wildflowers are used in zone 3 of the multi-species buffer adjacent to the agricultural crop. The prairie grass slows down water entering the buffer, traps sediments and chemicals, and provides diverse habitat for birds and other animals. The typical prairie grasses and wildflowers that do well in Minnesota are given in Table 4. They can be obtained from any of the prairie nurseries listed below.

<u>Agricultural crops for agroforestry</u>

There are a multitude of agricultural crops that can be used for intercropping and/or inter-cropping agroforestry systems. The choice of crop in Minnesota depends upon individual farmers' preferences, soils, and markets. The duration of inter-cropping opportunities varies with the spacing between the poplar rows in the field. Traditional 10 foot rows allow alley cropping for the first 2 to 3 years before tree canopy closure. Longer durations are possible with wider spacing such as 20 to 30 feet between rows. The following crops have been successfully used for inter-cropping with poplars in different parts of the world (Nair, 1993): barley, buckwheat, clover, corn, lespedeza, melons, oats, potatoes, rye, soybeans, sugar beets, sunflowers, vegetables, vetch and wheat. Almost any crop can be used in inter-cropping with poplar if properly designed. Of course, the seed of local varieties of the above agricultural corps is available throughout the state of Minnesota from farm cooperatives.

Planting Methods

Planting stock

There are a number of types of poplar planting stock that can be used to fit the application in Minnesota. There are unrooted hardwood cuttings and poles (whips), cut back rooted cuttings (called barbatelles), bareroot stock, softwood (greenwood) cuttings, container stock, and balled and burlap (B&B) stock. Each of these may suit certain planting purposes. However, the majority of poplars planted in Minnesota are either unrooted hardwood cuttings or bareroot stock. These preferences are due to cost and availability from nurseries.

Over the years the recommended practice of planting stock size has increased. Formerly, 8" unrooted hardwood cuttings were recommended, but now 10" unrooted cuttings are the standards. Because of increased deer browsing and warmer, drier weather conditions in recent years, larger unrooted stock (12 to 18" long) are now the recommended "BMP". Larger stock and bareroot stock grow larger, faster to minimize deer browsing during the establishment year. Containerized stock is recommended only for the aspen and aspen hybrid clones as these trees do not root readily from cuttings.

Containerized stock of hybrid poplar is sometimes used in harsh prairie soils (Oosten, 2006). Cottonwood and cottonwood hybrids grow "best" from bareroot stock in Minnesota, because warmer soil temperatures are needed for their root development. Cottonwood can also be grown from barbatelles, which are bareroot stock cut back to 1 foot in height.

Unrooted hardwood cuttings should measure from 3/8 to 3/4"" in diameter and should be stored in sealed plastic bags at 32 to 40 degrees F. The cuttings should be warmed to room temperature before planting for 5 to 7 days and should be soaked to ¾ of their length in the shade with the buds upright. Cuttings are ready for planting when the buds begin to turn green and when the roots begin to grow.

Bareroot stock and barbatelles, like cuttings, should be stored in a cool place before planting and then soaked in water at room temperature for a few days before planting. Containerized stock should be kept in dormant state until planting.

Time of planting

In Minnesota poplar planting should be in May to early June. Earlier guidelines that recommended planting in mid-April have led to much dieback in Minnesota due to late spring frost and freezes. The exception to this guideline is dormant container stock and B&B plants which can be planted in April. B&B stock can also be planted in autumn. Unrooted hardwood cuttings and bareroot stock should be planted when the soil is moist or when rain is expected. Container stock should be watered before planting. Planting stock should be covered with a tarp during planting. Success improves when soil temperatures are above 50 degrees F. Temperatures of 65 to 70 degrees are optional. In dry, prairie soils in northwest Minnesota bareroot stock is preferred over unrooted cuttings because the soils dry out before the unrooted cuttings become established .

Planting

Planting methods are critical to planting success. Planting unrooted hardwood cuttings can be done by hand or machine. The planting layout at the desired spacing should be marked in advance by hand with a hand operated distance measuring wheel and with biologically safe paint. For large tracts, a tractor driven marking device can be used. Unrooted cuttings should be planted with one or two buds exposed. **Cuttings must be planted upright.** A hand planting tool for cuttings works well and the soils should be pushed in against the cutting to fill air gaps. There are several makes of tractor mounted cutting planting machines.

Unrooted whips or poles should be planted at a depth of 2 to 3 feet. Except in very moist soils, they need to be planted with a hand-held power auger (6" diameter) or a tractor driven auger designed for post holes. In clay soils a larger hole is needed because the hole side may restrict root penetration.

Bareroot stock or barbatelles can be planted by hand or by machine. The stock should be planted slightly deeper that they grew in the nursery (about 1 to 2 inches). The stock can be shovel planted or planted by machine. There are planting machines that make a furrow to plant bareroot stock. With this machine it is crucial that each tree be planted upright in the furrow with a symmetric distribution of roots. If trees are not planted properly in furrows, roots grow horizontally and the resultant trees are not wind firm. This problem is common in Minnesota plantings.

For smaller tracts where there is a shallow hardpan layer in the soil or where the landowner wants early deep penetration of roots for environmental purposes such as phytoremediation or near livestock operations, auger planting is recommended. There are one-man, two-man, skid steer mounted, or tractor mounted augers available commercially or for rent. Many farmers already have a 3-point hitch tractor mounted post hole digger which works well. Bareroot stock or barbatelles are planted in a 6 inch to 1 foot hole dug to about 2-3 feet deep. The holes are backfilled with native soil, soil amendments or compost. Excess soil or amendments should be left above the ground line to allow for settling. Soil should be pressed around the stock to minimize air gaps. Slow release fertilizers such as 14-14-10 Osmocote (or comparable product) should be used with auger plantings. Regular agricultural or lawn fertilizers are **NOT** recommended because they are too harsh for developing roots. They are beneficial after the trees are established. Compost and mulches can be substituted for commercial fertilizers, but use of lawn clippings should **NOT** be used if "weed and feed" fertilizers have been used. These lawn clippings contain the herbicide 2-4 D which is harmful to young trees.

Planting Maintenance

Weed control

Competition of any kind will decrease poplar growth and survival. Weed control in the early years of poplar culture is essential. Weed control will be easier if good site preparation was done. There are a number of ways to control weeds depending upon the landowner's resources and philosophy. They include hand weeding, cultivation, mowing, cover crops, herbicides and mulching.

Hand weeding by pulling or string trimmer can be done on a small scale, but becomes a futile effort if the size of the planting exceeds one acre. Cultivation has been the traditional way of controlling weeds before the advent of chemical control. It can include hand hoeing, horse drawn cultivation, or tractor driven cultivation with a disc or rotovator. Cultivation should be shallow to minimize root damage. Several cultivation passes will be needed each year. Cultivation, although effective, has serious drawbacks as it is time consuming, expensive labor, equipment and energy intensive. Cultivation must be done carefully to minimize mechanical damage to trees during the repeated passes. It is not very effective during rainy periods.

Mowing can be used to control weeds and grasses as they compete for available moisture and provide habitat for damaging rodents. It also improves aesthetics. Tractor or ATV mounted mowers control weeds between rows and articulating mowers (i.e. weed badger) can be used within rows. Mowing has the same limitations as cultivation.

Cover crops can be used to minimize weed growth. They also prevent wind and water erosion and can be harvested at the end of the season to decrease cover for rodents. Alfalfa and clover are legumes and can contribute to overall site nutrition. Some studies suggest that cover crops decrease production of poplars due to competition for water and nutrients other than nitrogen.

Herbicides are the most common means of weed control in Minnesota today. The number of labeled herbicides for poplar culture has increased markedly over the years and there are never-ending changes in the formulations and company names. A comprehensive list of herbicides for poplar culture was presented by Dickmann and Stuart (1983), Boysen and Strobl (1991) and Dickmann et al (2001), but many of these chemicals are now different and unfavorable experiences with certain chemicals when used for poplar culture have modified the recommendations.

The landowner should always consult the herbicide label before applying. Herbicides can be used exclusively or in coordination with cultivation. The current recommended herbicides for poplar culture in Minnesota are given in Table 5. It is note-worthy that certain chemicals should be used **only on upland** sites and certain chemicals may have to be avoided in wellhead protection areas (see: www.pca.state.mn.us). Again, always consult the label!!

Experience suggests that the most effective herbicide weed on control in Minnesota is a tank mix of imazaquin (Sceptor) and pendimethalin (Pendulum) sprayed over the top of newly planted cuttings. This application is followed later in the season by one or two applications of fluazifop (Fusilade) for control of grasses. Troublesome invasive weeds like Canadian thistle are controlled with directed sprays of clopyralid (Transline). These weeds are almost always a problem in Minnesota and they are on Minnesota's noxious weed list.

Mulching is an effective weed control method if done properly. Many materials can be used for mulch such as sawdust, wood chips and bark. Straw is not good mulch as it harbors rodents that damage trees. Mulching is an organic approach to weed control. Organic mulch must be at least 3 to 4 inches thick to keep weeds from growing through it. Mulch tends to use up available nitrogen when it decomposes. Either fertilizer or compost must be applied when mulches are used. Mulching can be done with landscape fabrics. Fabrics should be selected with good water penetration and should be black or weeds will grow through it. Organic mulches can be used upon fabrics to hold them down. Cost is a major drawback of the landscape fabrics. Plastic landscape mulch should be avoided as it is a petroleum product and it breaks into pieces over time creating a littered landscape. They also improve habitat for damaging rodents. Moreover, pulp companies do not want plastic in the crop delivered to the mill.

Planting protection

Insects

There are hundreds of insects that attack poplar leaves and stems, but there are only a few major threatening insects of concern in Minnesota. With a changing climate that number may increase due to longer generation times.

Cottonwood Leaf Beetle: Cottonwood leaf beetle (CLB) is a native beetle of major concern in Minnesota. It attacks young trees in nurseries, plantings, and natural stands. It is a native insect that is common along all Minnesota river bottoms. It can deform trees and with repeated defoliation kill young trees.

Identification: CLB can be identified by its yellow masses on the underside of poplar leaves. The larvae are dark brown and white and about ¼ inch long. They feed in clusters and consume the entire leaf except the large veins. The adult beetles are black-spotted intermixed with ivory-to-gold stripes. The adults also feed on leaves.

Control: CLB can be controlled with a broad spectrum insecticide, but this practice is not recommended as a BMP. A better practice is to spray commercial Bacillus toxin (B.t.) formulations. Although safe and specific, this practice has been challenged by bee keepers in Minnesota. B.t. applications are only effective during the first generation of CLB in the year – monitoring is needed to determine this time. CLB can do much damage in a short period of time. Another new strategy is to soak un-rooted hardwood cuttings and/or whips or bareroot stock with Bayer's Admire Pro insecticide. This practice has proven effective for protecting recently planted poplars. Follow instructions on the label for safe use. There are some clones that are more resistant to CLB, although these clones have not been planted widely in Minnesota.

Forest Tent Caterpillar: The larvae of the native forest tent caterpillar attack and defoliate all poplar species in Minnesota.

Identification: The forest tent caterpillar larvae are bluish-black and are about 1 to 2 inches long with white key-hole like markings on its back. They occur in large migrating clusters on the stems and leaves of poplars. The egg masses are black-gray plastic like that over-winter on shoots and twigs of poplar (and other tree species).

Control: It is not practical to control this insect on a large scale, but it can be controlled with a broad spectrum insecticide. This practice is not a BMP, however. B.t. formulations can be used when the insect is at the early larval stages.

Poplar Borer: The larvae of poplar borer feed on the stems, roots and branches of trees 3 years old or older. Boring can weaken the tree and cause the tree shoot to break off. Fungi enter the cavities created by them and woodpeckers damage tree stems infested with them.

Identification: The poplar borer leaves sap spots and mixed sap-frass oozing from holes in poplar stems. Often the bark is split where the borer enters the tree. The poplar borer larvae is yellow-white and legless, and is up to 1 ¼ inches long. One must cut the stem open to find it.

Control: The best means of control of the poplar borer is by removing heavily infected trees. Insecticides can be used in the spring to kill adults, but this is not a BMP.

BMP's for poplar insects

When poplars are planted in large areas, it is inevitable that insect problems will develop. The BMP for minimizing insect outbreaks is to plant small block mosaics of several pest resistant poplar clones rather than large monoclonal blocks. Planting 20 acres in separated blocks helps minimize insect outbreaks. Controlling weeds helps minimize insect outbreaks, and planting honeydew sources increases the number of parasitic wasps that feed on poplar insects. Examples of honeydew producers are clover, vetch, and willows. Another approach is to maintain pine stands near poplar stands for habitat for predatory birds such as blackbirds that eat poplar insects.

The key to minimizing insect pests in poplar culture is to maintain plant and animal genetic diversity and maintain trees in vigorous condition as insects are more common in stressed poplar stands. For more detailed information on poplar insects and integrated pest management of poplars see: Dickmann and Stuart (1983), Ostry et al (1988), and Dickmann et al (2001).

Diseases:

There are 5 major poplar diseases in Minnesota:

Septoria Leaf Spot:

Identification: *Septoria* leaf spot is the most important disease of hybrid poplars in Minnesota. It does not affect the native cottonwood or aspens. *Septoria* begins as a circular leaf spot up to one-half inch in diameter with brown or yellow margins and becomes irregular large spots with dark centers and tan centers. Then the disease progresses to branch and stem cankers. The cankers are blackened depressed areas with cracks. The cankers are often associated with the base of branches. The disease in advanced stages causes dieback of branches and stems.

Control: There is no control for *Septoria* except to plant *Septoria* resistant hybrid poplar clones or plant native poplars that are not susceptible.

Melampsora Leaf Rust:

Identification: *Melampsora* leaf rust is a major problem for poplars in Minnesota causing premature defoliation and decreased growth. It is often associated with environmental stress. It is identified by yellow or orange pustules on the undersides of the leaves.

Control: *Melampsora* can be controlled by planting resistant clones and maintaining healthy stress-free plants.

Marssonina Leaf Spot:

Identification: *Marssonina* leaf spot causes leaf spots and lesions on new shoots. In severe cases it causes premature defoliation. It is characterized by small, brownish, circular to angular leaf spots one-eight inch in diameter, and can have a yellow hole around the spots.

Control: Disk between tree rows in late fall to decrease *Marssonina* inoculation. Plant *Marssonina* resistant clones.

Venturia Shoot Blight:

Identification: *Venturia* is a leaf and shoot blight that affects aspens and hybrid poplars. It has irregular brown or black areas on leaves in spring and then causes blackened curled shepherd's crook shoots later on.

Control: *Venturia* is usually only a minor short term problem. Plant *Venturia* resistant clones.

Hypoxylon Canker:

Identification: *Hypoxylon* canker is an important disease of the aspens in Minnesota. It is first characterized by sunken yellow-orange areas on stems and branches. In advanced stages it has blistered bark and gray pegs on the back.

Control: There is no known control of *Hypoxylon*. Pruning young branches can prevent its spread. Plant resistant aspen clones and maintain healthy stands.

For more detailed coverage of diseases in poplars see Ostry et al (1989), Callan (1998), and Dickmann et al (2001).

Animal browsing

Animal browsing is a serious problem in poplar culture in Minnesota especially when preferred foods are in short supply. The greatest culprits are beaver and white tailed deer that have high populations in Minnesota. Beavers do extensive damage in riparian zones and white tailed deer (and sometimes moose) browse heavily on newly planted stock. Whitetail bucks also rub their antlers on small diameter poplars in the autumn. Mice and voles girdle trees during the establishment year and rabbits girdle or clip off young poplar stems during winter.

Control of animals is difficult. Direct control by hunting and trapping is probably most effective, but if these measures are not an option there are some indirect approaches. For example, there is some degree of preference for smooth barked poplar clones by white tailed deer. Native cottonwood trees and hybrids are less susceptible to browsing and buck rub than hybrid poplars. Good weed control discourages browsing by rodents that inhabit weeds and grasses. Raptor poles also encourage raptors to hunt for rodents in poplar plantings. Commercially available deer repellants that can be either painted or sprayed on trees are available. Some repellents are effective, but their duration is usually limited and they can be expensive if multiple applications are needed. Tree Guard from Becker Underwood Co., Ames, IA is a repellent that has been used successfully.

There are more expensive options available to control browsing. Some fencing approaches work well on small areas. Mesh fence, high-tensile fence, and 3-D polytape fences have all been used successfully. The polytape fences must be maintained regularly to be effective and are not effective in deep snow. Tree shelters can be used on small plantings around animal confinements or phytoremediation projects. Shelters are deployed until trees are large enough to discourage animals. Animal browsing does tend to be more of a problem with smaller plantings. When landowners have large acreages, damage tends to be on the edges and not significant.

Fertilization

Poplars have a high nutrient requirement to maintain maximum productivity. If nutrients or water are limiting, poplar growth is significantly decreased. Applying fertilizers when water is limiting has little benefit. Nitrogen is the most limiting nutrient for poplar culture in Minnesota, given soils of pH from 6.0 to 7.5. There are some soils in Minnesota where micronutrients are limiting. There have been some major changes in recommendations of fertilizers and fertilizer approaches for poplars in recent years. Fertilization recommendations are one of the most important aspects of “BMP’s” for poplar culture in Minnesota. The goal of fertilizer BMP’s is for poplar culture to maximize the amount of nutrients taken by poplars, and minimize the quantities of nutrients (especially nitrogen and phosphorous) that run off into nearby streams or to the groundwater. The idea is to fertilize poplars, not groundwater!

The first consideration the landowner must address is the pH of the soils where poplars are to be planted. If the soils are acid, liming will be necessary to bring the soil pH up to 5.0 or higher (preferable pH 6.0). If the soils are alkaline, (>pH 8), elemental sulfur can be added or acidic nitrogen fertilizers can be used to decrease soil pH over time. The formulation of the fertilizer, the quantity of fertilizer, the timing of fertilization, and the number of applications are all important considerations for BMPs.

Fertilizers can be applied at any time during the rotation and once the poplars are established soil analyses coupled with foliar analysis are the most economical and effective way of diagnosing nutrient deficiencies.

Formerly, when foliar nitrogen levels were below 2%, nitrogen fertilization was recommended. The standard recommendation was 150 lbs of nitrogen per acre applied as granular ammonium nitrate. Fertilization was often done once in a rotation at rates of 100 to 400 lbs per acre with the assumption that the high rates would produce a long term fertilization effect. Unfortunately, many of the nutrients were not captured by the trees with this approach and much of the nitrogen and phosphorous ended up in the groundwater, or surface water runoff. (Brooks et al, 2005, Perry et al, 2001, Tolbert et al, 2000).

Typical formulations currently used in the Lakes States are granular urea (45-0-0) or liquid urea – ammonium nitrate in solution (28-0-0) in irrigation systems (called fertigation). More frequent applications at lower rates such as 50 to 150 pounds per acre promote maximum growth and avoids groundwater degradation. Costs of application increase with this approach but the costs of the fertilizer are probably less because of the increase in efficiency of the nutrient uptake.

The "BMP's for fertilization of poplars in Minnesota is annual applications of 50 pounds of nitrogen per acre applied as urea (45-0-0), or as a fertilizer blend (18-18-18) with 2.5% sulfur with diammonium phosphate, urea, potash, and ammonium sulfate. The ammoniacal nitrogen and sulfate are added to decrease pH. If micronutrients are limiting, a commercial miro-nutrient product should be added at the same time (Coleman et al, 2006). These "BMP's will protect Minnesota's water quality while effectively increasing poplar production.

In wellhead protection areas a new slow release fertilizer is now also recommended. This product is called ESN (Environmentally Smart Nitrogen); it is urea coated with a thin polyurethane film, and looks promising after tests by Minnesota Department of Agriculture in wellhead areas in west central Minnesota.

When animal manure is being used as fertilizer, "BMP's" are:

- Test manure for nutrient content
- Calibrate manure application equipment
- Apply manure uniformly
- Inject manure where possible
- Avoid applying manure on sloping, frozen soils
- Apply at recommended nutrient rates

These practices will help decrease nitrogen loss to the environment (Randall et al, 2003).

<u>Irrigation</u>

Irrigation of poplars is not common in Minnesota, and may not be economical for traditional wood products. Poplars will respond to irrigation on drier sites with fertile soils, or where fertilizer is applied with irrigation water. Irrigation is beneficial where groundwater is below 10 feet. Where practical, irrigation can increase poplar biomass production by up to 50%.

Irrigation of poplars for non-traditional purposes such as animal liquid wastewater use, municipal wastewater reuse, or for phytoremediation is very practical, and is an essential component of the agroforestry system. The quantity of water applied through irrigation depends upon soil texture, soil drainage, poplar clone, tree age and planting spacing. Weed control in an irrigated system is very important in order for irrigation to be effective.

There are a variety of irrigation systems available. Traveling gun irrigation systems and above sprinkler systems are practical only in the establishment year because distribution of water is a problem in older trees. Understory sprinkler systems and drip irrigation systems are most effective for poplar culture. Aboveground sprinklers may not be permitted for some wastewater applications because of airborne pollutant issues. Below ground drip systems are effective, but often maintenance problems below ground limit their use. The "best" available system in use is an above-ground drip system with pressurized emitters at each tree location. Drip systems can put out up to ¾ gallon of water per hour and have been used extensively in the Western US in poplar culture. These systems are also used for phytoremediation applications throughout the Midwestern US. Poplar stands that are over 5 years old can take up over 40 inches of water in a growing season. Mid-day water use by a 5 year old poplar trees can be 3 to 4 gallons per hour, and the overall water use of a poplar tree is reported to be between 5 to 15 gallons per day depending upon tree size and environmental conditions (Dickmann et al, 2001). Thus, poplar trees are very effective at taking up water for environmental remediation purposes.

<u>Thinning</u>

Thinning is not a regular practice in poplars stands in Minnesota, because it is often uneconomical with today's operational costs. Thinning can be effective to decrease overcrowding so that larger diameter trees are free to grow and to remove un-merchantable trees for bioenergy or firewood at mid rotation. The larger trees can then be harvested for higher value products at the end of the rotation. Thinning should not be done until the tree crowns have closed and diameter growth rate has declined. Thinning can be accomplished by thinning every other row, or by selectively removing smaller trees to open up the poplar stand. Thinning can be done with traditional harvesting equipment, by horse, or by hand with a chain saw and small tractor.

<u>Pruning</u>

Pruning is the removal of lower dead or dying branches to enhance stem wood quality. It is used successfully throughout the world where poplars are grown for solid wood products. It is not economical if high value clear wood products are not the end product goal. Thinning and pruning can be used to convert a poplar stand established for pulpwood to a stand that will yield solid wood products at rotation age. Pruning is usually done in late spring or early summer so wounds can heal quickly and epicormic branching is minimized. Pruning can be done by hand with pruners or by using hydraulic pruners. The branch should be cut leaving a short branch stub that will quickly heal. Cutting flush with the stem causes undue injury.

The following pruning regimen is recommended for poplar stands with a 20 year rotation age for solid wood products:

- Do not prune in the first 5 years; unwanted sprouts can be removed, or trimmed and/or forked tops corrected (sometimes termed singling and shaping)..
- Prune only the lower 1/3 of the crown plus additional trimming (5 to 10 years)
- Prune lower 2/3 of crown leaving upper 1/3 at harvest (15 to 20 years).

Not all trees need to be pruned. Pruning should be done on only the highest valued crop trees.

Coppicing

Poplars sprout readily from the stump or root collar when cut; this resprouting is known as coppicing. Coppicing should be done in the dormant season. Aspens and aspen hybrids also sprout vigorously from root suckers throughout the stand after harvest. Coppicing offers the landowner an inexpensive way to re-establish a stand without replanting. Most landowners choose to replant new genetically improved clones rather than coppice. But, coppicing can be attractive because coppice shoots grow vigorously and are very productive. Coppice stands are usually more productive than the original stand in the first 5 years after harvest.

Coppicing is used effectively for environmental plantings where water uptake and contaminant remediation is the goal rather than merchantable wood products. Coppice can also be useful for bioenergy and animal fodder.

Organic poplar farming practices

Organic poplar farming practices require a different perspective on maintenance of poplar plantings. Organic poplar farming is a sustainable form of producing wood products without the use of herbicides, pesticides, or fertilizers. Organic farmers typically rely more on labor intensive practices and try to minimize energy intensive machinery based cultural practices. Organic poplar farmers rely on rotation of crops with trees, shelterbelts for livestock shelter, intercropping of poplars and agronomic and horticultural crops, green manure for building soil organic matter, livestock manure and composting for fertilizer, and cultivation for weed control. Wood harvested would typically be used for firewood (bioenergy) and farm construction. Emphasis is often more on livestock production rather than traditional wood product production.

Harvest Options

Overview

The harvest of poplars depends upon the final product goal, and the economic position and philosophy of the landowner. There are a whole range of harvest options ranging from low tech labor intensive methods to the use of sophisticated high tech harvesting machines and chippers. Poplar stands should be harvested when their average annual growth increment begins to decline over time. This time frame depends upon the original planting spacing and growing conditions.

Regardless of the harvest methods there are some key "BMP's" for harvesting poplars. First, the trees should be cut low to the stump to maximize harvest volume and to promote stump resprouting (coppice). If the entire tree is not removed from the site, the tops, branches, and other slash should be spread on the site to promote decomposition (unless the site will be replanted immediately afterwards). Poplar logs should not be decked along roads for lengthy periods of time because they are subject to bacterial stain. Secondly, in Minnesota poplars should be harvested in the winter months to minimize soil compaction and to maximize resprouting. Poplar trees resprout better if cut during the dormant season from November through April. If resprouting is not desirable, harvest can be done in summer on sites where soils are firm. Use of a tracked harvester minimizes compaction. Harvesting by hand with a chainsaw followed by horse skidding minimizes site damage and is a more sustainable practice. If a whole tree chipper or harvester is used, winter is a better time for harvest because foliage is left on site to recycle essential nutrients and organic matter. Another important practice relating to harvest is stream crossings should be minimized and a buffer along the stream should be maintained. Any harvest near a stream should be by hand and with minimum disturbance such as horse skidding or cable skidding.

The choice of a harvest system depends upon the planting area, tree size, and landowner objectives. For small areas a labor intensive (i.e. human intensive with minimum mechanization) approach is efficient. For medium size blocks a small tractor (or a horse) can be used to skid tree length logs. But, for large areas a highly mechanized approach may be necessary that may include a feller buncher or tracked harvester, a grapple or cable skidder, and/or a stationary chipper. For bioenergy there are mobile whole tree chippers under development. These approaches vary greatly in cost and energy use. There are logging contractors available for hire throughout Minnesota that can meet the landowners' objectives. It is wise for the landowner to have a contract with a contractor specifying volume to be removed, property boundaries, and environmental considerations. Usually these contracts should include a partial up-front payment to the landowner.

Post harvest options

One common post-harvest option is to kill the stumps of the former planting with herbicide and replant with new improved poplar clonal stock. Stumps could be removed by a bulldozer, but that option is not economical in Minnesota. When stumps are killed and the site replanted, the new rows are offset and planted within the old rows. This approach eliminates the option of mowing as a weed control strategy because of the presence of stumps.

Another post harvest option is to maintain the subsequent stand as a coppice stand. Each stump will have multiple stems and the coppice stand will be more productive than the old stand. This approach may be utilized for bioenergy, phytoremediation, or riparian wildlife plantings because multiple stems are not problematic. If single (or double) stems are the goal of the landowner, it will be necessary for the landowner to thin the multiple stems back to one or two stems during the first or second dormant season after harvest. This practice can be achieved by hand or hydraulic pruners mounted on a farm tractor. Again, the choice would depend upon the landowners' resources and philosophy. If sawlogs or veneer is the product objective, probably the replant option will be most effective, because of potential defects associated with the cut stumps and problems associated with multiple stems.

Utilization Opportunities

Growth and yield of poplars in Minnesota

Growth and yield of poplars in Minnesota depends upon geographic location, site quality, clone, age, spacing, and silvicultural conditions. Poplars typically grow in height from 2.5 to 7.0 feet per year. In the Minnesota Regional Poplar Plantation Network several clones averaged from 5.0 to 6.5 feet per year for 10 years (Netzer et al, 2002).. Diameter growth ranged from 7 to 9 inches in 10 years. At Blackduck the average annual diameter growth of all poplar clones ranged from 0.5 inch per year to about 0.9 inches per year at Granite Falls. Diameter growth at a clonal trial with newly selected poplars at Westport averaged 4.25 inches in six years for all 60 clones tested: but 12 clones had diameters over 4.7 inches, and 2 clones over 5 inches in 6 years (Riemenschneider et al, 2001). Eighteen new clones grew taller than the designated DN 34 standard clone, and several clones outgrew the standard in diameter. New cottonwood clones are expected to grow even faster.

Biomass yields in the Regional Poplar Plantation network ranged from 2.6 to 4.5 tons per acre in 8 to 10 years, and currently operational plantings in Minnesota yield over 4 tons per acre. A goal of 6 tons per acre has been set by geneticists. Individual tree dry weights for the Plantation

Network for our newly recommended clones are given in Table 6. There is a large range of productivity across Minnesota depending on site, location, and clone. Some trees attain 200 lbs of leafless dry weight in 10 years. Thus, 10 trees of this size would yield a ton of biomass (Table 6).

Volume growth for poplars in Minnesota varies from 100 to 350 ft^3 per acre per year in 10 to 20 years. There are reports of annual volume growth of 100 ft^3 per acre in 5 years, to over 400 ft^3 per acre per year after 12 years (Dickmann et al, 2001). Hybrid aspen plantations grow from 100 to 200 ft^3 per acre per year, and two hybrid aspen clones adapted to Minnesota grew 259 ft^3 per acre per year in Iowa (Hall et al, 1982). We can expect improved volume growth with the new clones grown under the BMP's recommended in this manual.

<u>Traditional wood products</u>

The most important and frequently used poplars in Minnesota are the aspens -- trembling aspen and bigtooth aspen. However, research has shown that hybrid poplars, cottonwood, and cottonwood hybrids are good substitutes for aspen in utilization for traditional wood products (Balatinecz et al, 2001).

Pulp and paper:

The most important use of poplar wood in Minnesota is pulp and paper. Poplar wood substitutes well for aspen for pulp and paper products, and is being grown for pulpwood extensively in west central Minnesota by the forest products industry. Distance from the railhead or the pulp mill remains the most important factor in the extent of poplar use for pulp and paper.

Solid wood products:

Poplar wood has been used locally for construction lumber since the early days of settlement in Minnesota. It is also presently used for a broad range of the solid wood products including pallets, crates, boxes, and furniture components. The advent of modern dry kilns with improved drying capabilities has opened up more poplar lumber opportunities including molding, paneling, flooring, fine furniture, picture frames, and decorative boxes (Kretchman et al, 1999).

Composite products:

Poplar wood is increasingly used for composite wood products. These products are in high demand for construction in the housing industry. Again, poplar wood is a good substitute for aspen wood in composite products. These products include particleboard, fiberboard, waferboard, oriented strandboard, veneer, plywood, and composite lumber such as laminated veneer lumber (LVL), laminated strand lumber (LSL) and composite I-beams. The demand for these products will only increase as modern drying methods and new glues are developed.

Bioenergy:

There has been a renewed interest in bioenergy since the price of gasoline and natural gas has increased in the last year. Bioenergy from poplars is a concept that has been around since the oil embargo of 1974 (Meridian Corp, 1986), but until now the low price of fossil fuels has kept bioenergy from poplars from advancing. Poplar wood, chips, or pellets can be burned directly for energy production or mixed with coal to produce electricity (Licht and Isebrands, 2005). This co-firing approach is a cleaner, cheaper, and more environmentally acceptable than burning coal alone. Bio-fuels are renewable fuels, that are neutral with respect to carbon dioxide emissions, thus, decreasing greenhouse gas emissions in accordance with the international Kyoto Treaty on

Climate Change. Bio-fuels are also now eligible for tax incentives in Minnesota (see economics section later).

Another bioenergy application for poplar wood is the small scale close-coupled gasifier for home and farm use. Moreover, hundreds of farmers in the Midwest are burning wood pellets in small scale indoor and exterior home and farm wood burning stoves. Many are burning a combination of wood pellets and corn as an alternative energy source and to save money. Poplar wood contains between 7000 and 8000 BTU per pound depending on its moisture content. Therefore, a ton of poplar contains nearly 16 million BTU's of energy (Isebrands et al, 1979). That energy equivalent is over 4 million kilo-calories, or 133 gallons of gasoline, or more than 16000 cubic feet of natural gas. Poplar plantings in Minnesota produce, as outlined above, more than 4 tons per acre per year with expectations of that figure to rise to 6 tons per acre per year with new poplar clones in the future. Therefore, bio-energy from poplar at current prices is now a viable alternative crop in Minnesota. The Laurentian bio-energy project in Hibbing is one such example.

Animal feed products:

The foliage from poplars is rich in nitrogen and protein and can provide a valuable source of animal feed. Poplar leaves are used for fodder in many parts of the world especially for sheep and goats, and may have potential for organic farmers in Minnesota (Balatinecz et al, 2001).

Agroforestry benefits:

There are numerous agroforestry benefits that can add income for the landowner. The primary benefit of poplars is livestock protection that increases production efficiencies such as daily milk yields of dairy cattle, as well as weight gains on cattle, swine, and poultry. An often overlooked gain is the energy savings in summer and winter provided by windbreaks and shelterbelts around animal confinements (Malone and Abbott-Donnelly, 2001). Other agroforestry related gains for landowners are enhanced agricultural crop yields, crop diversification, and less crop damage, enhanced snow (moisture) management, enhanced property values, and income from wildlife hunting fees.

<u>Intangible Products</u>

Many of the intangible products from poplar planting are well known, but haven't until recently provided income for the landowner.

Soil erosion control:

Millions of tons of topsoil are eroded down major river drainages in the US. The Mississippi River watershed, of which the Minnesota river is a part, accounts for the deposition of huge quantities of soil carrying nutrients such as nitrogen and phosphorous as well as herbicides and pesticides to the Gulf of Mexico. This erosion has led to an enormous "dead zone" of thousands of square miles where animal and plant life are minimal. The erosion is largely caused by more than a century of clearing of streamside forests (largely native cottonwoods and willows) for agriculture. Millions of acres along the Minnesota River are part of this national problem. Planting multi-species riparian buffers with trees and shrubs (including poplars and willows) and grasses along the streams stabilize the streambanks, decrease soil erosion, and thereby decrease total nitrogen and phosphorous runoff by 60% (Schultz et al, 2004). Moreover, the buffers increase the quantity of total organic carbon retained in soil compared to agricultural crops while providing more biodiversity including beneficial soil microbes and greater fish, small mammal, and bird populations than agricultural crops. The USDA currently provides assistance for farmers establishing and maintaining buffers on their farms. Poplars are an important part of this multi-species buffer approach. In this way, poplar planting is serving society and landowners are able to realize some income for their efforts.

Protection:

Protection plantings of poplars and other tree species and shrubs on farms have been used over a century in Minnesota to enhance farm operations. Windbreaks and shelterbelts consisting of single or multiple rows of trees and/or shrubs are established for environmental purposes around farmsteads and agricultural fields. They moderate heat in summer and cold in winter for people on livestock, thereby enhancing land value, beauty, noise reduction, and wildlife habitat. Around fields they protect crops by decreasing soil erosion and moisture loss, serve as sites for animal manure removal, and produce biomass for bioenergy and wood. These plantings increase crop yields by decreasing stress on crops. They also can produce salable small diameter wood products from "timberbelts" in a short time frame, while improving wildlife habitat and other environmental benefits. Again, it is difficult to place a value on these environmental benefits. If poplars could be harvested from protection plantings after a reasonably short rotation, society would gain both the environmental and economic benefits of such efforts.

Wildlife benefits:

The issue of wildlife benefits of poplar planting is a controversial one in Minnesota. Some agency professionals and citizens see poplar culture as monoculture of non-native species that have adverse effects on native plants and animals and thereby having a negative effect on plant an animal diversity. (Center for Rural Policy and Development, 2001). If even aged monocultures of non-native species were the strategy of agroforestry practices, those critics would have a valid point. They are not!

A multitude of research studies throughout the Midwest and the world have shown how "BMP's" of poplar plantings can increase wildlife diversity. For example, streams with native multi-species riparian buffers exhibit greater stream invertebrates and fish species diversity, more vole and mouse species, and 5 times the number of bird species as agricultural rowcrops or grazed riparian areas (Schulz et al, 2004). Well established riparian buffers are excellent winter habitat for upland birds in Minnesota (Edwards, 2005). Multi-species multi-row shelterbelts of trees and shrubs with corridors provide wildlife excellent refuge from predators, protection from inclement weather, and safe travel between habitat areas (PFRA, 2002).

Numerous studies with poplars have shown the positive effects on maintaining heterogeneous plantation edges, multiple age class vegetation structure, and diverse understory vegetation on small mammal use, breeding bird habitat, bird diversity and wintering habitat use (Mertens, 1999, Hanowski et al, 2002, Moser et al, 2002, Moser and Hilpp, 2003, Hanowski et al, 2005). Properly designed poplar plantings using BMP's will increase wildlife habitat in Minnesota agroforestry systems (Wisconsin DNR, 1990, Williams et al 1996, Gordon and Newman, 1997).

Livestock operations benefits:

There are an increasing number of livestock confinement operations in Minnesota and throughout North America. Some of the most challenging interrelated problems associated with these confinements are odor and animal waste management. These problems are due to increased size of operation, suburban expansion into agricultural areas, odor transmission across open landscapes, and minimum regulatory requirements (see Minnesota Department of Agriculture, 1994 and websites).

Multi-species shelterbelts that include poplars and willows as well as long lived conifers and shrubs can mitigate these animal confinement problems in several ways by odor plume interception, disruption and dilution (Tyndall and Colletti, 2006). Shelterbelts dilute manure-generated odor compounds in the atmosphere, deposit dust by decreasing wind speeds, physically intercept dust that is the primary cause of odor, and absorb volatile compounds into the tree. The shelterbelts also provide visual and sound barriers to animal feeding operations that are appreciated by neighbors.

Emerging Opportunities

Carbon sequestration:

There is considerable interest in the potential of short rotation woody crops including poplars for carbon sequestrations credits. Carbon credits are traded daily on the Chicago Board of Trade, but at low prices due to political uncertainties. The potential for receiving carbon credit income for afforestation projects in the future remains to be seen, although the American Farm Bureau currently offers some carbon credits in some states. However, poplar plantings grown under BMP's can increase soil organic carbon over time, and more importantly sequester carbon by replacing fossil fuels with a renewable biofuel and/or by increasing the long term storage of carbon in solid wood products (Tuskan and Walsh, 2001). Annual aboveground carbon accumulation in shelterbelts has been estimated as up to 10 tons of carbon per acre per year. Tree plantings will also reduce carbon dioxide use on farms by lowering heating costs, decreasing snow removals, reducing fertilizers, lowering feeding demands for livestock, and improving water use efficiency.

Phytoremediation:

Poplars and willows are the most important trees in Minnesota for phytoremediation applications. Their rapid growth and high water use make them excellent choices for phytoremediation of industrial wastewater, wellhead areas, animal confinement wastes, pesticide spills, and leaking landfills in Minnesota. The phytoremediation technologies include streamside buffers, vegetation filters, directed plantings and vegetation caps. These technologies are emerging in Minnesota. Probably the most promising agroforestry applications in Minnesota are the use of poplars to phytoremediate recycled animal wastewater and manure near confined animal feeding operations (CAFO's) and recycled wellhead water that is contaminated with high levels of nitrates and pesticides.

Other opportunities:

There are several other emerging opportunities for agroforestry related businesses in Minnesota. The high cost of gasoline and the increased corn-based ethanol industry in Minnesota has opened up the opportunity for cellulose biomass to ethanol conversion. The technology for this process has been available since World War II, but was not cost effective until now.

The other emerging biomass related industry is "bio-refining". Bio-refining is the refining of biomass (i.e. from poplar plantings) to produce value-added chemicals including bioplastics without using additional fossil fuel energy.

Economics

The economics of growing hybrid poplar is a difficult subject that has been studied by many for years, but it depends upon so many ever-changing variables (Rose et al, 1981, Lothner, 1983, Boysen and Strobl, 1991, AURI, 1993, Oosten, 2006). It is complex because the revenues from a multi-year poplar crop are not generated until harvest and the costs to establish and maintain the crop occur long before rotation age (Oosten, 2006). Moreover, the costs vary markedly with soil type, productivity, location including distance from markets, fossil fuel costs, government programs and landowner objectives. There are also many risks in growing poplars including weather, pests and diseases (Volney et al, 2005).

Some of the important variable costs to consider in an economic analysis of poplar growing include: land, planting stock, fuel, labor, site preparation and weed control, fertilizer, irrigation, harvesting, property tax, income tax, and insurance as well as market values (revenues) for products at harvest (Rose et al, 1981, Lothner, 1983). These variables have not changed much over the years, but the absolute costs and revenues have changed markedly. For example, fuel costs in Lothner's (1983) analysis were estimated at $1.00 per gallon compared to over $3.00 per gallon at the time of this writing. Moreover, fuel prices have doubled in just the last 2 years making long distance hauling of some poplar products uneconomic. Thus, market driven changes in poplar utilization are occurring rapidly throughout North America (Stanton et al, 2002). Further changes can be expected if poplar wood can be used for producing transportation fuels or if landowners can get credit for carbon sequestration in the future (Tuscan and Walsh, 2001). Government programs may also change to include more cost share for poplar planting establishment costs for conservation efforts.

Oosten (2006) uses a discounted cash flow method available on the internet to calculate future costs and revenues of poplar growing over time. Costs of poplar growing are changing so rapidly in Minnesota we refer the readers of this "Best Management Practices" poplar manual" to an up-to-date University of Minnesota hybrid poplar economics webpage located at the following website:

www.cinram.uwn.edu/srwc/economics

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Useful Websites

Agroforestry:
- www.aftaweb.org
- www.cinram.umn.edu
- www.unl.edu/nac/conservation/
- www.extension.umn.edu/agroforestry
- www.centerforagroforestry.org

Confined Animal Feeding Operations (CAFO):
- www.ipic.iastate.edu/events/EPA/EPAinfo.html

Ducks Unlimited:
- www.dcks.org

Fertilizer:
- http://www.pca.state.mn.us/water/tmdl/index.html
- http://www.agrium.ca/ESN/index.jsp

Herbicides/Pesticides:
- www.wssa.net
- www.greenbook.net

Invasive Plants:
- www.ipaw.org
- www.dnr.wi.gov/invasives
- www.invasive.org

Minnesota Hybrid Poplar Research Cooperative:
- http://www.auri.org/poplars/default.htm
- www.hybridpoplar.org/

Natural Resource Conservation Service (NRCS):
- http://www.mn.nrcs.usda.gov/news

Pheasants Forever:
- www.pheasantsforever.org

Poplar Council of Canada
- www.poplar.ca

Prairie Farm Rehabilitation Administration, Ag & Food, Canada:
- www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1186517615847&lang=eng

Riparian Buffers:
http://www.puyallup.wsu.edu/agbuffers/
http://www.buffer.forestry.iastate.edu/
www.unl.edu/nac

Shelterbelts:
www.agr.gc.ca/pfra/shelterbelt.htm.

Short Rotation Forestry:
www.esf.edu/willow/
www.auri.org/poplars/default.htm

USDA:
Conservation Programs:
www.nrcs.usda.gov/programs

Conservation Reserve Program (CRP)
www.fsa.usda.gov/

Offices:
http://offices.sc.egov.usda.gov/locator/app

USFS, North Central Research Station Publications
www.ncrs.fs.fed.us

Water Quality (TMDL's):
www.epa.gov/watertrain/agmodule
www.nrcs.usda.gov/technical/
www.epa.gov/owow/nps/cwact.html
www.agrium.ca/ESN/index.jsp

Wellhead Protection – Minnesota:
www.mda.state.mn.us/appd/waterprotect.htm
www.mrwa.com

Wildlife Financial Resources:
www.fws.gov/partners/
www.wildlifehc.org

List of Tree Nurseries

Cascade Forestry Nursery, Inc
21995 Fillmore Rd
Cascade, IA 52033
563-852-3042

Dean Schumacher's Nursery
RR 2 Box 10
Heron Lake, MN 56137
507-793-2288

Hramor Nursery
2267 Merkey Rd
Manistee, MI 49660
231-723-4846

Lee Wholesale Nursery
Fertile, MN 56540
218-574-2237

Ludholz North Star Acres, Inc.
420 Hwy A
Tomahawk, WI 54487
715-453-2976

Lincoln-Oakes Nurseries
P.O. Box 1601
Bismarck, ND 58502-1601
710-223-8575

List of Prairie Seed Nurseries

Ernst Conservation Seeds
9006 Mercer Pike
Meadville, PA 16335
Tele: 814-336-2404
www.ernstseed.com

Lawyer Nursery, Inc
950 Hwy 200W
Plains, MT 59859
Tele: 406-826-5700
www.lawyernsy.com

Prairie Moon Nursery
31837 Bur Oak Lane
Winona, MN 55987
Tele: 507-454-5238
www.prairiemoon.com

Prairie Nursery, Inc
P.O. Box 306
Westfield, WI 53964
Tele: 608-296-2741
www.prairienursery.com

Prairie Restorations, Inc
P.O. Box 327
Princeton, MN 55371
Tele: 763-389-4342
www.prairieresto.com

List of Photos
(Available from coordinators)

List of Tables

Table 1. Native poplar species in Minnesota

Species	Common Name
Populus balsamifera	balsam poplar
Populus deltoides	eastern cottonwood
Populus grandidentata	bigtooth aspen
Populus tremuloides	quaking aspen

Table 2. List of recommended poplar clones for agroforestry applications in Minnesota by region of state and site.

Clone Name (#)	Parentage	Native (Y/N)	Site	Region of State
Balsam poplar 1)	*Populus balsamifera*	Y	Shelterbelt	North
Crandon	*P. alba x P. grandidentata*	N	Upland	South
D105	*P. deltoides*	Y	Riparian	South
51-5	*P. deltoides*	Y	Upland	South
252-4	*P. deltoides*	Y	Riparian	South
7300501	*P. deltoides*	Y	Upland	South
80x00601	*P. deltoides*	Y	Upland	South
DN2	*P. deltoides x P. nigra*	N	Upland	North, West
DN5	*P. deltoides x P. nigra*	N	Upland	North, West
DN34(Eugenei)	*P. deltoides x P. nigra*	N	Upland	South, West
DN70	*P. deltoides x P. nigra*	N	Upland	South, West
DN154	*P. deltoides x P. nigra*	N	Upland	South, West
DN164	*P. deltoides x P. nigra*	N	Upland	South, West
DN170	*P. deltoides x P. nigra*	N	Upland	South, West
DN177	*P. deltoides x P. nigra*	N	Riparian	South, West

I 45/51	*P. deltoides x P. nigra*	N	Upland	South, West
NE222 (Caudina)	*P. deltoides x P. nigra*	N	Upland	South, West
NE264 (Volga)	*P. deltoides x P. nigra*	N	Upland	North, West
NM2	*P. nigra x P. maximowiczii*	N	Upland	South, West
NM6	*P. nigra x P. maximowiczii*	N	Upland	North, West
Northwest	*P. deltoides x P. balsamifera*	Y	Shelterbelt/ Upland	North
Brooks #6 2)	*P. deltoides x (P. laurifolia x P. nigra)*	N	Shelterbelt	North
Walker 2)	*P. deltoides x (P. laurifolia x P. nigra)*	N	Shelterbelt	North
Trembling aspen	*P. tremuloides* hybrids	Y	Shelterbelt/ Upland	North

1) *P. balsamifera* selections – Canada
2) Available in Canada

Table 3. Some Native Willows for Riparian Buffer Plantings in Minnesota

Common Name	Scientific Name	Plant Form
Peachleaf willow	*Salix amygdaloides*	Tree
Bebb's willow	*Salix bebbiana*	Shrub
Pussy willow	*Salix discolor*	Shrub
Heartleaf willow	*Salix eriocephala*	Shrub
Shining willow	*Salix lucida*	Shrub
Black willow	*Salix nigra*	Tree

Table 4. List of Prairie Grasses and Plants for Prairie Restoration and Riparian Buffers in Minnesota

Common Name	Scientific Name	Plant Type
Big bluestem	*Adropogon gerardii*	Grass
Side-oats grama	*Bouteloua curtipendula*	Grass
Canada wildrye	*Elymus Canadensis*	Grass
Switchgrass	*Panicum vigatum*	Grass
Little bluestem	*Schizachyrium scoparium*	Grass
Indian grass	*Sorgastrum nutans*	Grass
Butterfly weed	*Asclepias tuberose*	Forb
Smooth blue aster	*Aster laevis*	Forb
New England aster	*Aster novae-angliae*	Forb
Sky blue aster	*Aster oolentangiensis*	Forb
Prairie tickseed	*Coreopsis plamata*	Forb
Purple prairie clover	*Dalea purpurea*	Forb
Pale purple coneflower	*Echinacea pallida*	Forb
Ox eye sunflower	*Helianthus helianthoides*	Forb
Western sunflower	*Helianthus occidentalis*	Forb
Rough blazing star	*Liatris aspera*	Forb
Prairie blazing star	*Liatris pycnostachya*	Forb
Marsh blazing star	*Liatris spicata*	Forb
Wild bergamont	*Monarda fistulosa*	Forb
Foxglove beardtongue	*Penstemon digitalis*	Forb
Prairie cinquefoil	*Potentilla arguta*	Forb
Yellow coneflower	*Ratibida pinnata*	Forb
Black-eyed susan	*Rudbeckia hirta*	Forb
Cupplant	*Silphium perfoliatum*	Forb
Stiff goldenrod	*Solidago rigida*	Forb
Ohio spiderwort	*Tradescantia ohioensis*	Forb
Ironweed	*Veronica fasciculate*	Forb
Golden Alexander	*Zizia aurea*	Forb
Leadplant	*Amorpha canescens*	Legume
Canadian milkvetch	*Astragalus canadensis*	Legume
Round-headed bush clover	*Lespedeza capita*	Legume
Wild blue lupine	*Lupinus perennis*	Legume

Table 5. Recommended herbicides for use in poplar plantings in Minnesota.
Always check the product label before using – available online from company.
(site: U = upland; R = riparian)

Active Ingredient	Product Name	Manufac.	Application	Timing	Rate /Acre	Site
Clopyralid	Transline	Dow Agro Sciences	Selective - Post-emergent Thistle	Apply over top or directed	2/3 pt	U, R
Fluazifop p-butyl	Fusilade DX	Sygenta	Post-emergent grass control	Apply over top	Two / year 1) 12 oz. 2) 8 oz.	U, R
Glyphosate	1) Roundup	Monsanto	Site preparation	Apply when	¾-3 qt.	U
	2) Rodeo	Many others	Directed over Mature trees only	trees dormant		R
Imazaquin	Scepter 70 D G	BASF Ag	Pre- and Post-emergent	Broadcast before or after bud break Before rain or irrigation	2.8 oz.	U, R
Oxyfluorfen	Goal 2XL Plus	Dow Agro Sciences	Pre-emergent weed control	Pre-bud break or directed spray	4 pt. pre-emergent 2 pt. post-emergent plus surfactant	U
Pendimethalin	Pendulum 3.3 EC	BASF	Pre-emergent weed control	Broadcast before or after bud break Before rain or irrigation	3.6 to 4.8 pts	U

Table 6. Average growth and yield of individual trees of recommended poplar clones in Minnesota—ages 7 to 12. (from Netzer et al, 2002)

Minnesota Location	Clone	DBH	Height	Total Tree Dry Weight (lbs)	Age (yr)
Belgrade	DN 5	6.5	---	65	9
	NE 222	6.2	---	59	9
	DN 154	6.1	---	56	9
	DN 164	6.0	---	54	9
	I 45-51	5.9	---	52	9
	DN 34	5.1	---	36	9
	DN 2	5.0	---	35	9
Blackduck	NM 2	4.4	---	25	8
	DN 2	4.3	---	24	8
Cloquet	NE 222	6.6	---	68	11
	I 45/51	5.8	---	50	11
	NM 6	5.2	---	39	11
Grand Rapids	DN 5	6.0	---	54	7
	NM 6	5.9	---	52	7
	DN 2	4.2	---	22	7
	DN 164	4.2	---	22	7
	NE 222	4.1	---	21	7
	DN 2	8.2	---	112	10
	DN 5	7.8	---	100	10
	NM 2	7.3	---	86	10
	NM 6	7.2	---	83	10
	DN 34	7.1	---	81	10
Granite Falls	DN 34	8.7	57	131	10
	I 45/51	10.6	---	202	12
	DM 2	10.5	---	198	12
	DN 5	10.2	---	185	12
	DN 177	9.9	---	173	12
	NE 222	9.1	---	142	12
	NM 2	9.0	---	139	12
	DN 34	8.9	---	136	12
Milaca	DN 34	8.2	59	112	10
	I 45/51	6.5	---	65	10
	NM 6	6.4	---	63	10
	DN 5	5.7	---	48	10
	DN 2	5.7	---	48	10
	NM 2	5.6	---	45	10
	NE 222	5.6	---	45	10
	DN 2	5.7	---	190	12
	NE 264	9.8	---	169	12
	DN 177	9.7	---	165	12
	NM 2	8.6	---	125	12
	DN 5	8.0	---	107	12
	I 45/51	8.0	---	107	12
	NE 222	7.2	---	83	12

Table 7. English/Metric Forestry Conversion – Poplar Culture
(O.D. = oven dried; ca = about)

Multiply	by	To Obtain
inch	2.54	centimeter
foot	0.305	meter
mile	1.61	kilometer
ft^2	0.093	m^2
acre (A)	0.405	hectare (ha)
pound (lb)	0.454	kilogram (kg)
ton	0.91	tonne (mt)
gallon	3.79	liter
cord	3.6	stere (m^3)
M board feet	2.36	m^3 full sawn lumber
pounds/A	1.12	kg/ha
tons/A	2.24	tonne/ha
cord/A	9.15	stere/ha
cubic foot (ft^3)	0.028	m^3
cubic feet/A	0.070	m^3/ha
cord	ca.100	ft.^{3} (w/bark)
cord	ca. 2.8	m^3 (w/bark)
cord	ca.2.2	tons (green)
cord	ca. 2	tonne (green)
cord	ca.1.1	tons (O.D)
cord	ca. 1	tonne (O.D.)
ft^3	ca. 22	O.D. lbs
cords/A	ca.2.2	ton/A (green)
cords/A	ca. 4.9	mt/ha (O.D.)
cords/A	ca. 1.1	ton/A (O.D.)
cords/A	ca. 2.5	mt/ha (O.D.)

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