Review of Literature on Living Snow Fences

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Review of literature relevant to living snow fence Background on Living Snow Fences In areas where snowfall is prevalent, which includes most of New York State, snow blowing across open fields can create dangerous road conditions for the public, increase the number of accidents and injuries, and create expensive, time consuming and challenging situations for road crews to ameliorate. Snow and ice removal costs in the U.S. exceed $2 billion each year, while indirect costs related to corrosion and environmental impacts have been estimated to add another $5 billion each year. Factoring in costs associated with accidents and injuries would further increase this figure (Tabler 2003).

The threshold wind speed at which snow will begin to move is around 10 mph and the workability of wind speed is proportional to the cube of the wind speed (Tabler 2003), so slight reductions in wind speed can have significant impacts on snow movement and distribution. Structural or LSF have been used for a long time to reduce wind speeds and control blowing and drifting snow along roadways and other key locations. Structural snow fences that have been used include solid wood “Wyoming” snow fences, slatted wood, porous plastic, and most recently three dimensional structures like “snow snakes”. Structural snow fences can reduce blowing and drifting snow immediately after they are installed and are an effective choice in some situations, but they have a number of limitations. They have high establishment and maintenance costs because they are usually erected and removed each year, have to be stored, and have a limited useful life. In addition, a typical 4-foot high structural snow fence can quickly become buried in drifting snow, making them ineffective for the remainder of the winter.

An alternative approach to controlling blowing and drifting snow, as well as providing additional benefits to landowners and the environment, is to design and install living snow fences. These are plantings of trees, shrubs, or native grasses a short distance upwind of roads, homes, farmsteads, communities, or other important facilities (Gullickson et al. 1999). LSF can be cheaper to install and maintain than structural snow fences, have a greater height, and, therefore, can capture more snow. LSF are more aesthetically pleasing, and they have the potential to provide benefits such as wildlife habitat, CO_2 capture, and woody biomass for renewable energy.
While LSF have many positive attributes, they also have limitations and are often misunderstood. Much of the previous work on LSF has been done using slow-growing species that require two or more widely-spaced rows for effective control and take 6 to 20 years to become effective (Tabler 2003, Gullickson 1999). These designs for LSF require large areas, which is a significant limitation in the northeastern United States where roadside rights-of-way are usually narrow and landowners are less willing to set aside wide strips of land. There are several options available to overcome these limitations, including the use of a single or closely-spaced double row of fast-growing willow

or other shrubs. Another approach that has been effective is to pay landowners to leave rows of standing corn in fields in years when it is grown in problem areas.

An appealing attribute of LSF is that they are made up of living plants, and if properly installed, they will be in place and function for decades. However, because they are living plants, they require more planning and care during installation to be successful compared to structural snow fences. Planning should include an assessment of the following factors:

- Blowing snow conditions at the problem area
- Determination of the best location and orientation
- Evaluation of growing conditions for plants
- Selection of the right plant material, and
- Proper site preparation for planting.

In addition, the concerns of landowners need to be addressed, since most LSF in the northeast are installed off the right-of-way. The different steps in the design and installation of LSF are often a barrier to their use because they initially appear complex, but once key principles are understood, many of these steps are easily implemented. The most important characteristics for effective LSF are high density of stems and branches during the winter, good height growth, relatively uniform density along the length of the plant, and an upright form. Many willows and other shrubs inherently possess several of these characteristics. Other plants can be used by selecting the right varieties, alone, or in combination, and using different management practices. For example, the density of willow snow fences can be varied by changing the spacing between plants, by coppicing to alter the number of stems and degree of side branching, and by varying the number of rows planted. Rates of establishment can be modified by changing the size of planting stock, correctly matching plant species to site conditions, which can often be quite harsh, and altering soil conditions and snow fence management techniques.

Despite the increased attention and application that LSF have received in other parts of the U.S., they are not widely used in the Northeast. This is due to a lack of knowledge about them among landowners and highway managers, lack of demonstration sites, limited data illustrating their impact and benefits, and hesitation among landowners to plant permanent strips to woody plants in their fields. However, there is an extensive amount of literature that is available on both structural and living snow fences.

Part 1 pulls together, in one location, the literature that is available on living snow fences. The available literature on LSF includes scholarly articles, books, fact sheets and pamphlets from state departments of forestry and departments of transportation, and general websites with information on the topic. The living snow fence topic includes such subjects as living snow fences, windbreaks, plant characteristics, design and effectiveness of LSF and windbreaks, and principles of snow movement. Searching for literature on LSF was accomplished by searching the available databases in the Syracuse University and SUNY-ESF libraries system. Databases searched included Agricola, BioOne, CSA Illumina, IngentaConnect, ProQuest Research Library, ScienceDirect, Scopus, SpringerLink, Web of Science, and WorldCat. Google and Google Scholar were also used to find literature on living snow fences, and often results from those searches linked to articles found in the aforementioned databases. The following search terms were used in all searches (and combinations of these terms were also used using Boolean logic and truncation where appropriate): living snow fence, living snow fence*, living snowfence*, snowfence*, windbreak*, living snow fence plant characteristics, windbreak plant characteristics, living snow fence plants, blowing snow, snow movement, and snow control. Once a relevant article or resource was located, an abstract was found and the citation for the article and abstract was added to the list of resources. If there was no abstract to be found on the web for an article, a brief summary of the article or web page was written highlighting its relevance to the living snow fence topic. Articles and information previously found about LSF were also added to the literature review, and abstracts were searched for and added as well. When abstracts were not available, a summary was created as mentioned before. Because of the relatively large number of items found in these searches, the literature is grouped by categories.

The categories are as follows:

- Blowing and Drifting Snow
- Controlling Snow
- Cost/Benefits/Effects
- Ecological and Agricultural Aspects
- Living Snow Fences
    - Design
    - Installation and maintenance
    - Plants
- Programs
- Research

Blowing and Drifting Snow

The literature in this category discusses different aspects of blowing and drifting snow. Blowing snow creates drifts that form in particular patterns and understanding this process helps in designing a living snow fence for specific sites. These articles articulate how snow is blown and forms drifts and how LSF or other barriers aid in preventing snow from piling up on major roadways.

Alhajraf, S. (2004). Computational fluid dynamic modeling of drifting particles at porous fences. Environmental Modelling and Software,19, 163-170. Retrieved from ScienceDirect. Elsevier Syracuse University, Syracuse, NY. 13 May 2009 http://www.sciencedirect.com/

Abstract: This paper introduces a computational fluid dynamic (CFD) model for two and three-dimensional simulation of wind blown particles such as sand, soil or snow. The model is based on the homogenous two-phase flow theory, where the flow field is predicted by solving Navier–Stokes equations for transient, incompressible viscous flow. The particle volume fraction is predicted by solving the transport convection/diffusion equation. Particles transported by suspension and by saltation modes are modeled separately and added to the transport equation as extra source terms. A new solid interface boundary is introduced to the flow computational domain as particles

accumulate to form deposition regions. The model treats control volumes fully blocked by particles as solid surfaces whenever the deposition conditions are satisfied. The transport equations are discretized in Eulerian reference frame using finite volume method. The model is used to simulate the flow field around fences for two applications, snow drift at single row fence and sand drift at double row fence. In both cases, the model shows good agreement with observations and a realistic behavior of the snow and sand particles that deposited at porous fences as compared with both field and wind tunnel measurements.

George, E.J., D. Broberg, and E.L. Worthington. (1963). Influence of various types of field windbreaks on reducing wind velocities and depositing snow. Journal of Forestry 61, 345-349. Retrieved from IngentaConnect. 13 May 2009 http://pi2.ingenta.com/

Abstract: Comparisons were made of wind velocities and snowdrift patterns on the windward and leeward sides of windbreaks and slat barriers of varying numbers of rows, designs., and densities. Density was determined by placing a dotted grid over a picture enlargement and then computing the space occupied. Windbreaks and barriers which were permeable in the lower half of the structure caused snowdrifts to form over a wider area than the less permeable ones. Such permeable structures also reduced most erosive wind velocities to a nonerosive rate. Between a series of windbreaks spaced 400 feet apart wind velocities and snowdrift deposits indicated the series had no cumulative effect on wind reduction. Proper tillage practices must still be used in conjunction with windbreaks or other structures to control wind erosion of fields.

Sato, Toshimi, et. al. (2002). New method for evaluation of blowing snow measures through cold wind tunnel experiment and CCD image analysis. Proceedings of the XIth International Winter Road Congress. Highway Research Board.

Abstract: This paper describes a new method by which the effect of poor visibility improvement of the blowing snow measures can be quantitatively evaluated through the analysis of CCD image of blowing snow occurring in a cold wind tunnel device. The new method enables the selection of the most effective measure dependent on the in-situ conditions before site installation.

Schmidt, R.A. (1982). Properties of blowing snow. Reviews of Geophysics and Space Physics 20(1), 39-44. Retrieved from Scopus. Elsevier. Syracuse University, Syracuse, NY. 13 May 2009 http://www.scopus.com/

Abstract: The size and shape of windblown snow particles determine not only the mass transported by turbulent fluxes but also the rate of phase change from ice to water vapor that occurs in this multiphase flow. These properties and particle densities dictate particle fall velocity and therefore the vertical distribution of mass and surface area, which strongly influence the gradients and fluxes of sensible heat and water vapor within the transport layer.

Shulski, M. and M. Seeley. (2003). Climatological characterization of snowfall and snow drift in Minnesota (for the design of living snow fences). Analysis of Snow Climatology. Minnesota Department of Transportation. 1 Oct. 2003. Retrieved from http://climate.umn.edu/snow_fence/intro.html

Summary: This article addresses the problem in the Upper Midwest of blowing and drifting snow on roads and highways and a solution to that problem. The solution involves building LSF along roadways, and this article discusses the reasons why the Minnesota Department of Transportation is planting LSF to control drifting snow. The article also discusses the importance of understanding certain climatological factors that need to be investigated to effectively design living snow fences.

Tabler, R.D. (1975, Jul.). Estimating the transport and evaporation of blowing snow. Proceedings of the Great Plains Agriculture Council Publication 73, Snow Management on the Great Plains Symposium, 85-104. Retrieved from CSA Illumina. Proquest. 13 May 2009 http://md1.csa.com/

Abstract: Complexity of the physical processes does not permit the transport and evaporation of wind-blown snow to be estimated from a purely theoretical analysis. This paper describes a simplified conceptual model based on the maximum distance that a particle can travel before complete evaporation, and derived from consideration of the consequences of a non- uniform particle size distribution. Model predictions agree well with snow accumulations measured at numerous sites in southeast Wyoming over several years. Results indicate a significant portion of the winter's precipitation is lost to in-transit evaporation on sites where snowfall is relocated by wind. An example is given of how this model can be used to assess effects of land management practices on the transport and evaporation of blowing snow.

Tabler, R.D. (1980). Geometry and density of drifts formed by snow fences. Journal of Glaciology 26(94), 405-419. Retrieved from Scopus. Elsevier. Syracuse University, Syracuse, NY. 13 May 2009 http://www.scopus.com/

Abstract: Presents results from studies of snow-drifts formed by vertical-slat 'Canadian' and horizontal-slat 'Wyoming' snow fences having 50% porosity and heights H from 0.8 to 3.8m, on nearly level terrain. Polynomial regression equations are fitted to drift profiles for both fence types.

Takeuchi, M. (1980). Vertical profile and horizontal increase of drift-snow transport. Journal of Glaciology 26(94), 481-492. Retrieved from Scopus. Elsevier. Syracuse University, Syracuse, NY. 13 May 2009 http://www.scopus.com/

Abstract: The horizontal distribution of drift flux was measured with snow traps along a transect parallel with the wind, beginning at an up-wind boundary that served as the starting point of drifting snow. Results indicate that drift-snow transport cannot be defined uniquely unless the drifting snow attains equilibrium (i.e. the snow profile is saturated).

Controlling Snow

Articles in this section are relevant to how snow can best be controlled. Most methods of controlling snow that are discussed are by the use of a living snow fence or windbreak. Examples of snow fences that are effective in controlling snow buildup on roadways are given.

Bilbro, J.D. and D.W. Fryrear. (1988). Annual herbaceous windbarriers for protecting crops and soils and managing snowfall. Agriculture, Ecosystems and Environment, 22-23, 149-161. Retrieved from Science Direct. Syracuse University, Syracuse, NY. 13 May 2009 http://www.sciencedirect.com/

Abstract: Annual herbaceous windbarriers can have certain advantages over perennial woody shelterbelts in that they are easier, faster and cheaper to establish, and may allow more flexibility in the farming operation. Their primary function is to reduce windspeed, which in turn generally improves growing conditions for the adjacent plants by improving temperature and moisture conditions. Annual windbarriers can be effective in increasing crop yields, controlling wind erosion, preventing sandblast damage to crop plants and trapping snow where it will be of maximum benefit in increasing soil water. Barrier porosity should be 65–75% for snow management and 40–50% for all other applications. Plants used should be as resistant to lodging as possible. Barriers should be comprised of two or more rows of plants, oriented perpendicular to the erosive or snow-laden winds (or in a serpentine manner if there is no predominant wind direction), spaced properly and established early enough to give the necessary protection to the adjacent area.

Blackburn, R.R., D.E. Amsler, and K.M. Bauer. (2003, 13-17 July). Guidelines for snow and ice control materials and methods. Presentation. 10th AASHTO/TRB Maintenance Management Conference. Duluth, MN: Midwest Research Institute.

Summary: This print-out of a presentation gives guidelines for snow and ice control on highways based on a study of tactics used to control snow and ice. There is information on what kinds of tactics to use for certain amounts and kinds of snow and ice, such as using chemicals. This presentation does not have any information on snow fences; however, the information provided would be useful for determining the value of snow fences, whether living or not, as an effective tactic in controlling snow and ice on highways.

Managing drifting snow. (2001, Sep.-Nov.). Technology News. 11 May 2009 Retrieved from http://www.ctre.iastate.edu/pubs/Tech_News/2001/sepoct/managesnowdrift.pdf

Summary: This newsletter discusses how to manage drifting snow by various methods, including living snow fences.

Minsk, L.D. (1998). Snow and ice control manual for transportation facilities. New York: McGraw-Hill, 15 May 2009 Retrieved from http://ntlsearch.bts.gov/tris/record/tris/00784107.html

Abstract: Though there has been a low level of research into improved techniques and equipment for snow and ice control since the end of World War II in the United States, and to a greater extent in Europe and Scandinavia, it wasn't until the last decade of the twentieth century was well advanced that a concerted effort to address this deficiency was initiated. Annual costs of snow and ice removal and control have been climbing for many years and now total well over $2 billion in the United States. With costs becoming an increasing burden, government agencies both large and small have realized that the lagging technology must be improved to cope with the

increasing demands for more efficient operations. Research has now resulted in better designs of equipment for the removal task. New technologies have introduced new practices which are now reducing the deleterious environmental consequences of the massive amounts of chemicals once used for deicing. The technology of snow and ice control is not static. Therefore the emphasis of this book is on the fundamentals of snow and ice control, that is, the available technology and the scientific underpinnings of that technology, rather than a cookbook account of what actions to take or what procedures to follow. In our view, this will better prepare those most intimately involved with the critical task of ensuring the best performance of our transportation systems under adverse winter conditions. The goal is to provide the reader with a firm foundation that will enable him or her to assess the value of current and proposed equipment and techniques.

Peterson, T.C. and R.A. Schmidt. (1984). Outdoor scale modeling of shrub barriers in drifting snow.Agricultural and Forest Meteorology 31, 167-181. Retrieved from ScienceDirect. Elsevier. Syracuse University, Syracuse, NY. 13 May 200 http://www.sciencedirect.com/

Abstract: Model shrub barriers one-twentieth the average height of corresponding mature plants were exposed to snow drifting on a frozen lake, to test the effects of barrier porosity and row spacing on snow accumulation. Single rows with porosities of 8, 15, and 23% produced drifts with average cross-sectional areas of 9H2, where H is model height, The area of the average deposition downwind of a 36% porosity model was 12H2. Total deposition behind two model shrub rows spaced 8, 10 and 14H apart, perpendicular to the wind, was greatest for the largest spacing. At this spacing, the minimum snow depth between rows was 0.5H. The experiments demonstrate the importance of maintaining porous barriers. Gaps, simulating shrub mortality, greatly reduced snow storage, especially during high winds. Results from this investigation indicate that a porous shrub in rows spaced at least 14 times the average barrier height, would provide good snow distribution for forage production between rows.

Tabler. R.D. (2006). Three-dimensional roughness elements for snow retention. Final Report FHWA-Wy 06/04F. Niwot, Colorado: Tabler and Associates. 15 May 2009 Retrieved from http://ntlsearch.bts.gov/tris/record/tris/01042044.html

Abstract: The objective of this study was to develop a practical and economical method of retaining snow along roadsides in order to reduce icing caused by blowing snow. Although multiple rows of conventional 4-ft snow fence could serve this purpose, it was hypothesized that a three-dimensional array of elements might be more effective and aesthetic, and might prove to be more economical. An idea leading to the research reported here was for tetrapodal elements constructed from 2" x 4" lumber, and this was later expanded to include the development and testing of tubular, wire frame-supported plastic netting. The study consisted of developing, testing, and comparing these alternative roughness elements. Conclusions from this study are as follows: The 3-ft-tall tetrapod developed in this study is an efficient design that minimizes costs for materials and labor. Tetrapods are the most costly element to fabricate and install and the physical structure of tetrapods presents a potential collision hazard to errant vehicles. Tank baffles are effective in collecting snow, but their cost is approximately twice that of tetrapods. Snow snakes are significantly less costly than tetrapod arrays, and their cost per unit volume of snow storage is comparable to that of conventional snow fence of equal height installed on wood or steel posts. The primary advantages of snow snakes over conventional snow fences are their unobtrusive appearance, and the fact that they present no hazard to errant vehicles. They also promote the reestablishment of vegetation by increasing soil moisture, providing shade, and by providing protection from wind and grazing animals. Snow snake drifts in medians would also help to restrain vehicles that would otherwise cross over into oncoming traffic.

Cost/Benefits/Effects

The literature contained in this section includes papers on the costs, benefits and effects of living snow fences. LSF can be costly and take a while to become effective, but they have many benefits such as being more aesthetically pleasing compared to structural fences and they add to the natural landscape. Also, how the living snow fence is designed will produce certain effects. Some of these papers discuss what happens to the snow when blocked by a snow fence and how this benefits roadways and crops.

Benefit/cost ratio economic analysis. (2004). ADOT Traffic Engineering Policies, Guidelines, and Procedures.

Summary: This document is a part of the larger Arizona DOT Traffic Engineering Policies, Guidelines, and Procedures document which serves "as a guide for department personnel and consultants for traffic studies, operation, and design." The economic analysis provides some information on how snow fences have aided in reducing the rate of accidents due to snowy pavement.

Bird, P.R. (1998). Tree windbreaks and shelter benefits to pasture in temperate grazing systems. Agroforestry Systems, 41(1), 35-54. Retrieved from SpringerLink. 13 May 2009 http://www.springerlink.com/

Abstract: The effects of windbreaks on pastures are reviewed, with an emphasis on temperate grazing systems. Mechanisms of plant response to shelter are dealt with in brief. Few papers on measured responses of pasture species to shelter were located in a search of the global literature for the period 1972–97. Except in cold climates, where the benefits of snow-trapping on water availability can be demonstrated, there were few reports of increased production of pasture in response to shelter. A significant result was obtained in a summer rainfall environment in Australia, where a 43% increase in wool production was obtained over three years in small plots sheltered with iron sheeting on the fences. The gain was attributed to increased pasture growth. In New Zealand, one study over three years with a narrow, permeable shelterbelt in a windy, dry summer environment showed a 60% increase in pasture growth in the sheltered zone. However, another study on a high rainfall site with a dense, wide shelterbelt found no substantial shelter effect on pasture. In dry, hot and windy climates there appears to be scope for protecting spray-irrigated pasture with windbreaks. The feasibility of evaluating shelter effects on pastures or crops from old windbreaks is questioned. Variability of soil over the site cannot be satisfactorily accounted for and there are problems in defining the true 'unsheltered' yield.
Shelter effects on pastures could best be determined by comparing production in small completely sheltered plots and open plots. Effects in and near the competitive zone should be measured for living windbreaks. Modelling could then be used to evaluate windbreak systems. We are not yet in

a position to provide unequivocal advice to farmers on windbreak outcomes for particular purposes or regions.

Brandle, J. and L. Hodges. (n.d.). Field windbreaks. Extension Publication EC1778. Lincoln, NE:University of Nebraska. 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/pages/ index.jsp

Summary: This brochure explains how field windbreaks can increase crop yields while at the same time reducing inputs and improving environmental quality and production efficiency.

Brandle, J.R. and S. Finch. (n.d.). How windbreaks work. Extension Publication EC1763. Lincoln, NE: University of Nebraska. 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/pages/index.jsp

Summary: In this brochure, learn how windbreak structure -- height, density, number of rows, species composition, length, orientation and continuity -- determines how effective the windbreak will be in reducing wind speed and altering microclimate.

Daigneault, W. and Betters D. R. (2000). A comparison of the economic efficiency of living and artificial snowfence designs for road protection. Western Journal of Applied Forestry 15(2), 70-74. Retrieved from Agricola. IngentaConnect. Syracuse University, Syracuse, NY. 11 May 2009 http://www.ingentaconnect.com/

Abstract: Both artificial and living snowfences are used to protect roads from blowing and drifting snow. This article evaluates and compares the economic performance of three snowfence designs--the Wyoming and double-row slatted artificial snowfences and a three-row living snowfence. The economic analysis evaluates the snowfences by applying four economic performance indicators: total net benefits, present net value, benefit/cost ratio, and annual breakeven benefits. The study uses snow removal savings and accident reduction benefit information from a case study in the state of Wyoming. The case study results show all the designs are economically efficient when used for road protection. However, the living snowfence outperformed the other designs in three of the four economic performance indicator categories. The largest proportion of total costs of the Wyoming and living snowfence are establishment costs whereas the bulk of total cost of the double-row slatted snowfence is for maintenance. The economic performance of all the snowfences is most sensitive to changes in their useful or effective lives. The procedures and general conclusions of the study can be applied to similar cases elsewhere.

Heisler, G.M. and D.R. Dewalle. (1988). Effects of windbreak structure on wind flow. Agriculture, Ecosystems and Environment 22(23), 41-69. Retrieved from Scopus. Elsevier. Syracuse University, Syracuse, NY. 13 May 2009 http://www.scopus.com/

Abstract: Functional effects of windbreaks are directly related to the effects of windbreaks on air flow. Additionally, the indirect effects of windbreaks on air temperature and humidity are interrelated with the effects of air movement. The horizontal extent of windbreak effects upwind and downwind is usually assumed to be proportional to windbreak height, h. Measureable

reductions in windspeed have been recorded as far as 50 h to the lee of windbreaks, and rarely, even farther. Reductions of 20% or more may extend to about 25 h from the windbreak. For windbreaks that are long relative to their windbreak height, the most important structural feature is porosity. Maximum wind reductions are closely related to porosity, with low porosity producing high maximum reductions. Barriers with very low porosity create more turbulence downwind than medium-dense barriers. The higher turbulence may result in recovery of mean horizontal windspeeds to upwind speeds closer to low-porosity barriers, thus resulting in a shorter protected distance. However, the reduction in protected distance with very dense windbreaks compared to medium dense windbreaks is much less than much of the older literature suggests. Turbulence in the approach flow reduces windbreak effectiveness, particularly at far downwind positions. The turbulence may be caused by thermal instability, a rough ground surface, or other upwind barriers to flow. Differences in approach-flow turbulence, differences in height of measurement relative to windbreak height and differences in vertical porosity gradients are responsible for much of the scatter in experimental data. There is a triangular 'quiet' zone below a line beginning near the top of windbreaks and extending to near ground level at a distance of about 8 h to the leeward. In this zone, the turbulent velocity fluctuations are reduced below values in the approach flow. Above and downwind of the quiet zone is a 'wake' zone with turbulent fluctuations greater than those in approach flow. The magnitude of turbulent velocity fluctuations in the lee of windbreaks is inversely proportional to porosity. However, there is a larger difference in turbulence generated between solid barriers and slightly porous barriers than between slightly porous and very porous barriers. Windbreaks generally reduce turbulent eddy length, thus increasing the peak frequency of turbulent velocity fluctuations, regardless of their structure. Peak frequency of velocity fluctuations close to windbreaks tends to increase with porosity.

Josiah, S.J., S. Prestin, and D. Gullickson. (n.d.). The value of managed snow: benefit/cost analyses of LSF in Minnesota. Journal Series No. 13256, Agricultural Research Division, University of Nebraska.

Abstract: This paper examines the benefits and costs of LSF in the Upper Midwestern United States. While LSF are often promoted as an effective and well- tested means to control blowing and drifting snow along public highways, their economic performance has not been adequately documented. A recent living snow fence establishment program in Minnesota (upper Midwestern United States) provided an opportunity to determine economic impacts. Project participants provided site and living snow fence project descriptions, road usage statistics, and establishment and maintenance costs for the areas to be protected. Using these data, quantities (in tons) of snow expected to be trapped by living snowfences before it reached roadways were calculated, and estimates for subsequent savings for snow removal determined. The United States Federal Emergency Management Agency (FEMA) Riverine Limited Data Benefit-Cost Module for Hazard Mitigation Projects was then used to develop benefit-cost information for each proposed project. Benefit:Cost (B:C) ratios for a sample of 44 sites averaged 29:1 on private lands, and 83:1 on public lands. These conservative analyses included only snow removal costs for an average winter snowfall accumulation season (32” or 0.81m), and used US$1/ton for snow removal costs (severe storms can cost from US$3-US$5/ton for snow removal). B:C ratios would likely increase if environmental benefits, or other benefits gained from avoiding road closures were included, such as reduced loss of commerce, and enhanced public safety, or if the snowfences generated income through the production of commercially valuable products.

Kelson, A.R., R.J. Lilieholm, and M.R. Kuhns. (1999). Economics of LSF in the intermountain west. Western Journal of Applied Forestry 14(3), 132-136. Retrieved from IngentaConnect. 13 May 2009 http://www.ingentaconnect.com/

Abstract: Past research has found that LSF are the most cost-effective option for controlling blowing snow along transportation corridors. Despite this, LSF are an underutilized forestry practice throughout much of the Intermountain West, even though these fences can be successfully maintained in the region's harsh climate. Decision- makers may be encouraged to establish more LSF in the region when economic efficiency gains can be demonstrated. Efficiency gains from living snow fences, evaluated using the annualized cost approach, demonstrate that the benefits to society outweigh the costs. An example is presented using an average-sized, 1,040-ft-long, 3 row snow fence, and a discount rate of 8%. To offset snow fence costs over a 50 yr expected life, the fence need only reduce traffic accidents by as little as one every 23 yr, or reduce snow plowing by about 6 hr/yr. Other likely but less quantifiable benefits make the benefits of LSF even more economical to society. Private expenditures may need to be subsidized if these social benefits are to be provided at optimal levels, however

Living snow fence reduces costs, maintenance. (2002, Apr.-Jun.). Technology Exchange Newsletter. 16 Oct. 2003 Retrieved from http://www.mnltap.umn.edu/Publications/Exchange/2002-2/SnowFence.html

Summary: This article discusses briefly the benefits and basics of design of living snow fences. It also describes the program developed in Minnesota to plant living snow fences, and the progress of the program at the time of publication (2002).

Snow control structures. (1997, Feb.). Road Talk 4.

Summary: This short article describes the trade-offs of building snow fences as opposed to simply using existing corn fields as a means of controlling accumulating snow. A permanent snow fence is the most cost effective in the long term scheme and the use of cornstalk is only cost effective for the short term.

Spielman, J. and J.A. Dickerson. (n.d.). Why plant windbreaks? Selling windbreaks in the Northeast states.

Summary: This article discusses the uses and benefits of windbreaks in the Northeast in an effort to persuade the public to plant them. Some of the reasons discussed are energy conservation, livestock and wildlife comfort, crop protection, and control of soil erosion.

Tabler, R.D. (2003). Controlling blowing and drifting snow with snow fences and road design. Final Report. Niwot, CO: Tabler and Associates.

Summary: This article discusses the benefits of snow fences along roadways, including reduction in snow and ice removal costs, vehicle crashes, road closures, and pavement maintenance costs. Snow fences greatly reduce drifting snow which leads to poor visibility and slush and ice build-up. The results of a study on the installation of snow fences along I-80 in Wyoming are reported. This snow fences installed in Wyoming have been very successful in exhibiting all the benefits listed, especially in reducing the cost of snow removal by equipment.

USDA Natural Resources Conservation Service. (2006, Nov.). Conservation Practices that Save: Windbreaks/Shelterbelts. Save Energy Save Money. 18 May 2009 Retrieved from http://www.mainerural.org/energy/fieldguide/windbreaks.pdf

Summary: This article describes how windbreaks, shelterbelts and LSF have helped reduce energy usage in residential areas, as well as in snow removal efforts.

Ecological and Agricultural Aspects

These articles discuss how LSF affect the ecology of the site and the importance of LSF to agriculture. Many of these papers discuss how windbreaks are beneficial to farms and other agricultural systems. The importance of agroforestry is also discussed and how LSF are a part of agroforestry and can be used to improve the local environment. LSF also aid in conservation efforts of wildlife and to help decrease soil erosion.

Brandle, J.R., L. Hodges, and X.H. Zhou. (2004). Windbreaks in North American agricultural systems. Agroforestry Systems 61(2), 65-78. Retrieved from Web of Science. ISI Web of Knowledge. Syracuse University, Syracuse, NY. 11 May 2009. http://apps.isiknowledge.com/

Abstract: Windbreaks are a major component of successful agricultural systems throughout the world. The focus of this chapter is on temperate-zone, commercial, agricultural systems in North America, where windbreaks contribute to both producer profitability and environmental quality by increasing crop production while simultaneously reducing the level of off-farm inputs. They help control erosion and blowing snow, improve animal health and survival under winter conditions, reduce energy consumption of the farmstead unit, and enhance habitat diversity, providing refuges for predatory birds and insects. On a larger landscape scale windbreaks provide habitat for various types of wildlife and have the potential to contribute significant benefits to the carbon balance equation, easing the economic burdens associated with climate change. For a windbreak to function properly, it must be designed with the needs of the landowner in mind. The ability of a windbreak to meet a specific need is determined by its structure: both external structure, width, height, shape, and orientation as well as the internal structure; the amount and arrangement of the branches, leaves, and stems of the trees or shrubs in the windbreak. In response to windbreak structure, wind flow in the vicinity of a windbreak is altered and the microclimate in sheltered areas is changed; temperatures tend to be slightly higher and evaporation is reduced. These types of changes in microclimate can be utilized to enhance agricultural sustainability and profitability. While specific mechanisms of the shelter response remain unclear and are topics for further research, the two biggest challenges we face are: developing a better understanding of why producers are reluctant to adopt windbreak technology and defining the role of woody plants in the agricultural landscape.

Clark, W.R. and K.F. Reeder. (2007). Agricultural buffers and wildlife conservation: a summary about linear practices. Fish and Wildlife Response to Farm Bill Conservation Practices. Ed. J.B. Haufler. The Wildlife Society, Technical Review 07-1, 45-55. 18 May 2009 Retrieved from http://www.fsa.usda.gov/Internet/FSA_File/chap_3.pdf

Abstract: Conservation practices such as filter strips, grassed waterways, buffers, contour strips, riparian buffers, windbreaks and shelterbelts are eligible under a variety of USDA programs. Most were originally designed to provide benefits regarding reduced soil erosion and improved water quality. Most often grasses, or mixtures of grasses and forbs, are used in these practices, although establishment of trees and shrubs is encouraged in some practices. The small area and high edge-area ratios limit the usefulness of these practices for wildlife. Scientific evidence suggests that enrolling land in linear practices has accumulated in recent years, although most studies still focus heavily on benefits to birds and do not address the larger questions of the animal communities. With careful planning and management, applying linear practices widely within an agricultural landscape could be expected to have positive wildlife benefits compared with continued intensive row cropping.

Ganguli, A., et. al. (2008, Dec.). When are native species inappropriate for conservation plantings? Rangelands, 27-32. Retrieved from BioOne. Syracuse University, Syracuse, NY. 12 May 2009 http://www.bioone.org/

Summary: This article is about whether native or nonindigenous tree species should be used in conservation plantings. The article briefly describes how certain species have been planted for soil stabilization and for living snow fences. It also contains a chart outlining the distribution and purpose (including windbreaks and living snow fences) for planting eastern red cedar seedlings in several states.

Johnson, R.J., M.M. Beck, and J.R. Brandle. (n.d.). Windbreaks and wildlife. Extension Publication EC1771. Lincoln, NE: University of Nebraska. 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/ pages/index.jsp

Summary: This brochure provides an overview of how windbreaks can benefit wildlife and what trees, shrubs and planting designs to consider for various wildlife habitats.

Josiah, S.J. and J. Kemperman. (1998, Nov.). Emerging agroforestry opportunities in the upper Midwest. Journal of Forestry. 4-9. Retrieved from Web of Science. ISI Web of Knowledge. Syracuse University, Syracuse, NY. 12 May 2009. http://apps.isiknowledge.com/

Abstract: Agroforestry, the integration of trees and shrubs into agricultural systems, is thriving in the upper Midwest because of changing farm economics, new plant materials, useful research results, and growing markets for specialty forest products. Shelterbelts, riparian zones, living snow fences, and short-rotation plantations all create opportunities for environmentally friendly profit. Agroforestry's transdisciplinary nature requires partnerships, however, and although more

landowners are practicing agroforestry, today's scattered installations need to be integrated into a systems approach if agricultural landscape management is to improve.

Long-term snow-fence experiments to examine effects of altered climate in arctic and alpine tundra. (1997). Tundra Ecosystem Analysis and Mapping Laboratory. 15 Feb. 2001. Retrieved from http://culter.colorado.edu:1030/Niwot/Snowfence/intro.html

Summary (from introduction): The response of ecosystems to altered winter precipitation patterns as predicted by current global change estimates is unclear (Walker et al., 1993). An experiment in the Colorado alpine and Alaskan Arctic is examining the short- and long-term effects of altered climate regimes on tundra vegetation (Walker et al., 1994). Large snow fences and small portable greenhouses are being used to examine the effects of altered snow regimes and air temperatures (Welker et al., 1997 submitted). Tundra vegetation communities do not equilibrate quickly because changes to the belowground resources and the substrate require long periods to adjust and a series of transient plant communities unlike existing ones may occur. For this reason, we have designed an experiment with the intent of observing ecosystem change over a much longer time period than the standard 3-5 year ecology experiment (Walker et al., 1994). The following web pages describe the experimental design and the short-term changes to the physical and biological components of the system. The experiment is part of the NSF-sponsored Long-Term Ecological Research (LTER) project on Niwot Ridge, CO (NWT LTER), and the International Tundra Experiment (ITEX) (Molau and Molgaard, 1996) at Toolik Lake, AK.

Quam, V.C., et. al. (n.d.). Windbreaks in sustainable agricultural systems. Extension Publication EC1772. Lincoln, NE: University of Nebraska. 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/ pages/index.jsp

Summary: Information on integrating windbreaks and agroforestry practices into sustainable agricultural systems to enhance the local environment and add profitability.

Sampson, N. (1992). Forestry opportunitites in the United States to mitigate the effects of global warming. Water, Air and Soil Pollution 64, 157-180. Retrieved from SpringerLink. 12 May 2009 http://www.springerlink.com/

Abstract: There are a variety of opportunities in the United States to expand the area of trees and forests, and to improve their growth, that could have significant impact upon the annual uptake of atmospheric CO2. Work coordinated by the American Forestry Association has attempted to quantify those opportunities, and demonstrate what kinds of costs and benefits might result from an attempt to begin implementing them. The first section of the work, reported in this paper, has focused on the opportunities that are seldom thought of as regular forestry- planting trees on marginal crop and pasture lands, increasing windbreaks and shelterbelts, growing trees as a biomass energy source, and improving urban tree canopies and placements as an energy-conserving measure. The benefits from such work include the C sequestered in the biomass and soils involved, as well as the carbon emission reductions achieved through energy conservation. These opportunities could add up to a total C impact per year in the range of 141 to 382×106t-somewhere between 10 and 30% of the current net C emission from fossil fuel in the United States. Additional work is underway to quantify the opportunities inherent in improving the management of existing forestlands, through more traditional forestry. The results of that work will be available in late 1992.

Schoeneberger, M.M. (1992). Enhancing biodiversity with and within agroforestry plantings. USDA Forest Service – National Agroforestry Center. Lincoln, NE: University of Nebraska. 13 May 2009 Retrieved from http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1027&context=usdafsfacpub

Abstract: Agroforestry is the deliberate introduction of multipurpose woody perennials (MWPs) into agroecosystems for the purpose of enhancing agricultural productivity, natural resource conservation, and human environments. This introduction promotes biodiversity within the agroecosystem and thus its sustainability. This biodiversity is only a fraction of its potential due to the limited number and arrangement of the MWPs currently used in agroforestry plantings. An expanded effort in nursery and agroforestry research and development along with nursery production of diverse, adapted MWPs will need to be pursued to fully capitalize on agroforestry's economic and ecological benefits. [Also, paper has section on living snow fences.]

Shelterbelts for dugouts. (2003). Indian Head, SK, Canada: AAFC-PFRA Shelterbelt Centre.

Summary (from introduction): Water supply has always been a primary concern of prairie producers. To secure a reliable source of water, many generations of farmers have developed farm dugouts. Trees planted around a dugout increase the quantity of water stored in the dugout and may help to improve water quality. The combination of trees and water greatly enhance an area for wildlife by providing a dependable water source and wildlife habitat. This brochure gives reasons for why a shelterbelt around a dugout is beneficial and instructions in the design and planting of such a shelterbelt.

Sykes, K.J. and M. Majeski. (n.d.). Agroforestry – What is it? Can you benefit from it? Forest Management Update 20, 35-41. 12 May 2009 Retrieved from http://www.na.fs.fed.us/pubs/fmu/i20/article5.pdf

Summary: This article provides a basic history and description of agroforestry. The purpose and benefits of windbreaks is discussed in detail with mention of living snow fences.

Living Snow Fences

This section includes papers on design, installation and maintenance of living snow fences, and plants that can be used in them. This section is split into the sub-categories: design, installation and maintenance and plants. Articles in these sub-categories overlap; articles listed in installation and maintenance will also be relevant to designing living snow fences.

Design

This sub-category includes literature on how to design a living snow fence and the many factors that must be considered in setting up the proper design for a specific site. There are examples of specific LSF and how they were designed.

Brandle, J.R. and H.D. Nickerson. (n.d.). Windbreaks for snow management. Extension Publication EC1770. Lincoln, NE: University of Nebraska. 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/pages/index.jsp

Summary: This brochure provides guidance for designing a windbreak to manage snow for a particular purpose such as spreading snow across a large area or confining it to a small area to capture moisture and control drift.

Gullickson, D., S.J. Josiah, and P. Flynn. (1999). Catching the snow with living snow fences. St. Paul, MN: University of Minnesota.

Summary (from inside cover): While the need for and usefulness of LSF is becoming increasingly well accepted, until now there has been no one comprehensive source of information to help those interested in properly designing, locating, and establishing living snow fences. This guide is designed to meet these needs. Proper location and design is particularly important to living snow fences, because improperly placed of designed plantings can exacerbate problems they were intended to solve. No abstract was available online; a request to Interlibrary Loan was made.

Josiah, S. and Mike Majeski. (2002). Living snow fences. CINRAM, University of Minnesota. Retrieved from http://www.extension.umn.edu/distribution/naturalresources/ DD7277.html

Summary: This article is about designing a living snow fence and a program to build fences. It also contains information about effective barrier height, density, length, setback distance and plant species to be used.

Kenney, W.A. (1992). The role of Salicaceae species in windbreaks. Forestry Chronicle 68(2), 209-213. Retrieved from Web of Science. ISI Web of Knowledge. Syracuse University, Syracuse, NY. 12 May 2009. http://apps.isiknowledge.com/

Abstract: Windbreaks and shelterbelts have long been known to provide valuable amelioration of the environment to reduce wind erosion; improve crop yields; reduce heating costs in buildings; protect livestock; control snow drifting; provide wildlife habitat; improve the aesthetics of rural landscapes; etc. The efficiency of a windbreak will be affected by many of its design parameters such as length, height, width, orientation and porosity. Different wind-control objectives will require different designs, particularly with respect to porosity. The specific implications for the use of poplars and willows in windbreaks are discussed in terms of these objectives and design characteristics.

LandOwner Resource Centre and University of Toronto's Faculty of Forestry. (1995). Designing and caring for windbreaks. Extension Notes. 18 May 2009 Retrieved from http://www.lrconline.com/Extension_Notes_English/pdf/wndbrk.pdf

Summary: The Designing and Caring for Windbreaks fact sheet produced by the LandOwner Resource Centre and the University of Toronto's Faculty of Forestry gives information on the

design of windbreaks and their uses. It contains a table of windbreak plant species and their respective densities. It also has a table that outlines how suitable each plant species is to specific Ontario soil types.

Martinelli, M. (1973). Snow fences for influencing snow accumulation. Rocky Mountain Forest and Range Experimental Station, Fort Collins, CO. Retrieved from CSA Illumina. ProQuest. 13 May 2009 http://md1.csa.com/

Abstract: The efficiency of snow fences depends on height, density and length of fence, bottom gap, length and maximum depth of lee drift, cumulative effect of a set of tandem fences, tilting of fence, terrain effects, and contributing distance. The snow fence project on Mount Bethel in central Colorado is a practical example of how some of the above items were used to design and lay out snow fences intended to reduce the amount of wind-blown deposited in the starting zone of an avalanche that crosses an interstate highway.

National Cooperative Highway Research Program Project. (2009). Designing for environmental stewardship in construction and maintenance. Environmental Stewardship Practices, Procedures, and Polices for Highway Construction and Maintenance. 25-25 (4). 12 May 2009 Retrieved from http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/3_10.aspx

Summary: Section 2 of Section 10 in chapter 3 of this compendium discusses how to design snow fences. LSF are discussed at length with guidelines on how to design a living snow fence and how to select tree and shrub species to plant; however, no specific species are named.

Planning farm shelterbelts. (2003, Feb.). Indian Head, SK, Canada: Agriculture and Agri-Food Canada-PFRA Shelterbelt Centre.

Because this document includes design and maintenance information, it is listed in both sections of this paper.

Summary (from introduction): Properly planned shelterbelts provide many benefits to farm families. They reduce wind, control blowing snow, protect livestock, buildings and gardens, and trap snow for dugouts. Shelterbelts also provide habitat for wildlife, decrease energy consumption and beautify the farmyard. This brochure outlines how to plan and design a shelterbelt for a farm. It also lists suggested plant species to plant and how to space them when planting.

Quam, V., et. al. (n.d.). Windbreaks for livestock operations. Extension Publication EC1766. Lincoln, NE: University of Nebraska 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/pages/index.jsp

Summary: This publication discusses how to plan and plant a windbreak that protects livestock in all seasons and provides long-term economic benefits to the landowner.

Scholten, H. (1981). Effect of field windbreak design on snow distribution patterns in Minnesota.

Agricultural Experiment Station, University of Minnesota Technical Bulletin 329. Retrieved from WorldCat. 12 May 2009 http://www.worldcat.org/oclc/7382012

No abstract or full text available online. [requested through ILL] Summary (from introduction): To help farmers design the best possible field windbreak, the author began a study during winter 1961-62, which extended through the January 1975 blizzard, to determine the effect of windbreak density on snow distribution patterns. Snow depth measurements and observations of existing, well-established windbreaks in east central, west central, and northwestern Minnesota were recorded periodically. To understand the results of this study, the reader should first know the important characteristics of the ideal field windbreak species, and how snowdrifts are formed behind field windbreaks.
Characteristics of plants (height growth, branching habits and rooting habits) used in windbreaks are discussed along with different row and tree spacing. Thinning and pruning of trees is also discussed. The tree species used in this study are the Siberian elm, green ash, and red pine, and there is mention of testing other species.

Tabler, R.D. (1984). Snow control with road design and snow fences. Presentation outline. Snow Removal and Ice Control Technical Institute, University of Wisconsin Extension, Madison, WI.

Summary: This document is an outline of a presentation and summarizes the purpose of snow fences and relates them to road design. Snowdrifts can be predicted so that better road planning can take place and snow fences can be built effectively. This presentation explains many mathematical equations that are used to make these snowdrift profile predictions as well as design the appropriate snow fence for a roadway.

Tabler, R. (1991). Snow fence guide. Washington, D.C: Strategic Highway Research Program, Washington, D.C. 14 May 2009 Retrieved from http://ntlsearch.bts.gov/tris/record/tris/00621080.html

Abstract: The Strategic Highway Research Program developed this guide on snow fence technology to cover everything maintenance personnel need to know in order to design and locate snow fences. This guide summarizes the results of research by SHRP and others over the last few years. A 21-minute video, 'Effective Snow Fences,' supplements this guide.

Tuskan, G.A. (1986). Wind tunnel simulations of snow load accumulations within six farmstead windbreak designs. Great Plains Agriculture 117, 257-258. Retrieved from Agricola. OCLC FirstSearch. Syracuse University, Syracuse, NY. 12 May 2009 http://newfirstsearch.oclc.org/

Summary: Experiments on design and configuration of farm windbreaks in North Dakota show that windbreak design does affect snow depth patterns around farm facilities. Three different windbreak designs were tested each with two different plant configurations (six-row mixed species arrangement and a two-row high density arrangement). Two different storm simulations were applied to each windbreak and data was taken (average snow depth, etc.). The two plant

configurations did not appear to differ in the amount of snow displaced, however there were differences in the different designs.

USDA Forest Service, Rocky Mountain Research Station and Natural Resources Conservation Service. (1998). Inside Agroforestry. Lincoln, NE, Winter 1997-1998 Retrieved from http://www.unl.edu/nac/insideagroforestry/1997winter.pdf

Summary: This newsletter contains articles about successful LSF and windbreaks. It also includes diagrams of examples of different heights and densities of snow fences which determine how much snow can be stored by such snow fence.

USDA National Agroforestry Center. (2000, Nov. 13). Living snow fences. 11 May 2009 Retrieved from http://www.unl.edu/nac/aug94/snowfences/snowfence.html

Summary: This fact sheet of sorts gives general information on living snow fences. It provides a listing of facts and disadvantages to living snow fences. Steps to planning and designing a living snow fence are outlined along with examples of living snow fence in Idaho. There are also recommended plant species for LSF listed.

Wight, B., T.K. Boes, and J.R. Brandle. (n.d.). Windbreaks for rural living. Extension Publication EC1767. Lincoln, NE: University of Nebraska. 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/pages/index.jsp

Summary: Learn from this brochure how to design a windbreak around a home, ranch, or farmstead to slow the wind, conserve energy, provide snow and dust control and improve working and recreation environments.

Windbreak density: rules of thumb for design. (2007, Sept.). Agroforestry Notes AF Note – 36.

Summary (from introduction): Information on appropriate windbreak density for specific purposes is readily available. For example, living snowfences, crop protection, and snow distribution designs each have different density recommendations. However, information on selecting species and spacing to achieve a specific windbreak density is more difficult to find.
Measuring or estimating windbreak density is another problem altogether. This Agroforestry Note provides some basic designs, including example tree species and spacing along with pictures of real windbreaks that represent the three primary ranges of density for which windbreaks are designed.

Installation and Maintenance
This sub-category contains literature on how to plant the living snow fence and then maintain it so that it remains effective. There are many aspects that must be considered and done to keep a living snow fence maintained, such as weed, insect, and disease control. Within many of these papers are suggestions of plants to use.

Barkley, Y.C. (n.d). Living snow fences. University of Idaho Extension Forestry. 15 May 2009. Retrieved from http://www.cnr.uidaho.edu/extforest/Living%20Snow%20Fences.pdf

Summary: This brief article describes how trees should be placed in the design of living snow fences, and this information is also included in a table that shows what kind of plants should be planted in single or twin rows in a high to low protection continuum. A second table listed suggested plants for each of the kinds of plants indicated in the first table.

Boehner, P., J.R. Brandle, and S. Finch. (n.d.). Windbreak establishment. Extension Publication EC1764. Lincoln, NE: University of Nebraska. 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/pages/index.jsp

Summary: This brochure provides information on planning and establishing a windbreak uniquely suited to a particular site, including site preparation, plant material selection, weed control and replanting.

Planning field shelterbelts. (2003, Feb.). Indian Head, SK, Canada: Agriculture and Agri-Food Canada-PFRA Shelterbelt Centre.

Summary (from introduction): Properly planned shelterbelts provide many benefits to farm families. They reduce wind erosion, control blowing snow, protect livestock, trap snow, and increase crop yields. Shelterbelts also provide diversification opportunities, habitat for wildlife, and beautify the farm. This brochure discusses planning, designing, planting, and maintaining a shelterbelt around a farm. It also gives specifics of recommended plant species and row spacing for certain species.

Shaw, D.L. (1988). The design and use of LSF in North America. Agriculture Ecosystems and Environment 22(3), 351-362. Retrieved from Web of Science. ISI Web of Knowledge. Syracuse University, Syracuse, NY. 11 May 2009. http://www.sciencedirect.com/

Abstract: LSF are rows of trees and shrubs planted to control snow along land transportation routes, and which have the potential to (1) provide snow control, (2) enhance wildlife habitat, (3) provide winter livestock protection, (4) furnish environmental beautification and (5) offer long-term economic benefits. Disadvantages include the difficulty of establishment on some sites, the length of time to reach serviceable height, the high initial cost as compared to some structures, the degree of maintenance during the establishment period and the amount of land required. Primary features of living snow fence location and design include (1) distance from road, (2) length, (3) species, (4) number of rows, (5) spacing and (6) wildlife components. Each of these is discussed at length. Maintenance, which is the effort required to obtain satisfactory survival and growth, can present a number of problems in arid regions with limited precipitation. In such areas, issues which must be dealt with include irrigation, weed control, and protection from grazing livestock, big game animals, rodents, hot, dry winds and grasshopper damage. Solutions to these problems are discussed.

Stange, C. and J.R. Brandle. (n.d.). Windbreak management. Extension Publication EC1768. Lincoln, NE: University of Nebraska. 13 May 2009 Retrieved from http://www.ianrpubs.unl.edu/epublic/pages/index.jsp

Summary: This brochure explains how to maintain the health and vigor of a windbreak throughout its life cycle; covers weed control, protection from large animals and rodents, corrective pruning, insect and disease control and property checmical use.

Streed, E. and J. Walton. (2001). Producing marketable products from living snow fences. St. Paul, MN: University of Minnesota. 13 May 2009 Retrieved from http://www3.extension.umn.edu/distribution/naturalresources/components/DD7646.pdf

Summary: "In 1999 the Minnesota Interagency Task Force on LSF published a technical guide called Catching the Snow With Living Snow Fences. That guide presents the most up-to-date information available anywhere in the country on designing successful LSF (LSFs). This publication is designed to serve as an additional chapter to Catching the Snow With Living Snow Fences, as well as a stand-alone publication for those who do not have the technical guide. It is not meant to repeat the topics covered in the technical guide, but rather to add information about producing marketable products in LSFs. The material presented here is the product of research by the Center for Integrated Natural Resources and Agricultural Management (CINRAM) at the University of Minnesota."

Windbreaks for conservation. (1974). Agriculture Information Bulletin 339, United States Department of Agriculture.

Summary: This booklet from the USDA gives information on the purposes of windbreaks, including living snow fences, and instructions for planning windbreaks for different purposes. Instructions on what kinds of trees to plant, how to prepare the land and plant the trees, and managing the windbreaks are provided. A listing, by regions in the US, of suggested plant species for windbreaks is also provided.

Windbreak/shelterbelt establishment. (2002). Natural Resources Conservation Service, Conservation Practice Standard, U.S. Department of Agriculture. 12 May 2009 Retrieved from http://efotg.nrcs.usda.gov/references/public/WI/380.pdf

Summary: This document is a scientific reference from the Natural Resources Conservation Service division of the U.S. Department of Agriculture and provides a listing of purposes of windbreaks/shelterbelts. It gives criteria that must be followed in building windbreaks/shelterbelts in Wisconsin, including: location, designing, managing snow deposition, species arrangement, and other matters. There are also guidelines for plans, specifications, operation and maintenance of windbreaks. Similar documents are available for other states.

Plants

This sub-category consists of papers on specific plants, such as poplar and shrub willow and their usefulness in a living snow fence.

Dickerson, J. (2002). Plant fact sheet: Purpleosier willow. U.S. Department of Agriculture Natural Resources Conservation Service. 13 May 2009 Retrieved from http://plants.nrcs.usda.gov/factsheet/doc/fs_sapu2.doc

Summary: This fact sheet on Salix purpurea L. describes how this plant can be used, how to plant it and its usefulness in creating a living snow fence.

Dickman, D.I., et. al. (2001). Poplar culture in North America. NRC Research Press, Ottawa, Ontario, Canada. 12 May 2009 http://books.google.com/books?id= GRtdQYO_ejUC&pg=PP1&dq=Poplar+Culture+in+North+America#PPP1,M1

Summary: This book describes the status and use of poplars in North America. It documents recent scientific and technological advances in studying poplars. The book also summarizes the practical knowledge on growing and using poplars, this includes living snow fences/windbreaks and biomass for energy. The book outlines the silviculture and ecology of poplars as well as characteristics of clones and cultivars used in North America.

Hall. R.L. (2002). Aerodynamic resistance of coppiced poplar. Agricultural and Forest Meteorology 3068, 1-20. Retrieved from ScienceDirect. Elsevier. Syracuse University, Syracuse, NY. 13 May 2009 http://www.sciencedirect.com/

Abstract: The aerodynamic resistance to the transfer of heat and water vapour, of a canopy of coppiced poplar (Populus trichocarpa×deltoides) was estimated as the sum of three components; the bulk leaf boundary layer, within-canopy, and roughness-sublayer resistances. These components were calculated from measurements of wind speed and leaf area distribution. Account was taken of enhanced transfer of heat and water vapour over momentum within the roughness sublayer. The resulting estimates of aerodynamic resistance, which are in agreement with values determined more directly from the flux–gradient relationship for sensible heat, are less than for momentum transfer calculated from the classical semi-logarithmic formulae.
Consequently, the excess resistance for coppiced poplar at this site was negative.

Trees and shrubs for prairie shelterbelts. (2001, Jan.). Indian Head, SK, Canada: PFRA Shelterbelt Centre.

Summary (from introduction): This booklet summarizes the characteristics and use of trees and shrubs produced by the PFRA Shelterbelt Centre for planting on prairie farms. The information is not presented as a detailed taxonomic description but is designed to provide the user with a means of identifying trees in established belts and in determining desirable species for new plantings.

Programs

The papers in this category include those describing living snow fence programs in different states. Many of these programs were started to alleviate the problems associated with blowing and drifting snow on roadways. These descriptions of programs list plants used, funding for the program, and successes and failures of the programs. Most of the programs are partnerships with the U.S. Department of Agriculture or the states' Department of Transportation.

Claeys, Tom. (2009). North Dakota living snow fence initiative. Report. Bismark, ND: North Dakota Forest Service.

Summary: This paper outlines how North Dakota began a living snow fence program and its progress from 1998 to 2009. The concept behind LSF and their benefits is explained, as well as the goal of the initiative. The report lists general locations of living snow fences, those involved in the task force, grant programs that have aided the initiative, and provides a listing of the things the initiative did right to begin a successful program.

Iowa Department of Transportation. (2002, Jul.). Iowa's cooperative snow fence program. 13 May 2009 Retrieved from http://ntlsearch.bts.gov/tris/record/tris/00782252.html

Abstract: While we can't keep it from blowing, there are ways to influence the wind that carries tons of blowing and drifting snow. Periodically, severe winter storms will create large snow drifts that close roads and driveways, isolate farmsteads and increase snowplowing. Many of these drifting problems happen in the same place year after year. Although there are no foolproof methods of wind and snow control, properly designed and maintained snow fences can reduce or eliminate these problem areas. This publication discusses the benefits of snow fences, then examines the types used by the Iowa Department of Transportation. Finally, it provides information about how individuals can get involved in the DOT's Cooperative Snow Fence Program.

Iowa Department of Transportation. (n.d.). Living snow fence pilot project – Pocahontas County, Iowa. Ames, IA.

Summary: This short paper discusses the planting of two LSF planted in Pocahontas County, Iowa through cooperation with the Iowa Department of Transportation and the Pocahontas County Conservation Board. The snow fences consist of prairie grasses, forbes and flowers that are planted near state highways. These snow fences were planted as pilot projects in hopes of planting more living snow fences.

Kansas Forest Service, Kansas State University, Manhattan, KS. (2006, Jan.). Living Snowfences in Kansas. 18 May 2009 Retrieved from http://www.oznet.ksu.edu/ library/FORST2/L744.PDF

Summary: This brochure outlines information about LSF in Kansas. It describes how the snow fences should be designed with suggestions of trees and shrubs to use. There are also diagrams of living snow fence designs, and there is information on obtaining assistance from the Kansas Forest Service in designing a snow fence.

Kuhn, G., D.P. Hanley and K.R. Gehrlnger. (2009). Davenport living snowfence demonstration: five-year update. Northwest Science 83(2), 163-168. Retrieved from BioOne. Syracuse University, Syracuse, NY. 12 May 2009 http://www.bioone.org/

Abstract: Snowfences are specialized windbreaks that divert drifting snow so it will accumulate in a predictable location. They are used commonly in areas with significant snowfall such as the Great Plains and upper mid-west, but are very uncommon in eastern Washington.
The purpose of this planting was to display establishment and initial growth in this portion of the country using technologies developed elsewhere. Snowfence demonstrations in southeastern Idaho and a small-scale dry land test plantings near Ritzville, Washington led to an interagency snowfence demonstration project north of Davenport, Washington. The project demonstrated new establishment technology and the value of living snowfences in this dry cropland region.
Sixteen snowdrift sites in Lincoln County were identified by road maintenance personnel from the Washington State Department of Transportation. In April 2003, we planted 532 trees and installed fabric mulch on four 268-meter long rows at the selected demonstration site. While the project's primary purpose was to demonstrate feasibility, the trees' yearly growth was also documented. After five years tree height, crown width, and survival rates (100%) were greater than expected, suggesting that living snowfences can be successfully established in this area of the country. Also after five years, the snowfence started to catch drifting snow. The successful establishment and growth of this demonstration planting resulted in living snowfence demonstrations near Anatone, Washington and Athena, Oregon. Landowners and professionals working with landowners were encouraged to incorporate windbreaks into their conservation measures.

McLawhorn, N. (2003, Apr. 1). Snowdrift Control. Transportation Synthesis Report Wisconsin Department of Transportation.

Summary: This document summarizes living snow fence programs in states other than Wisconsin and serves as an aid to the state of Wisconsin for developing their own program. It also summarizes programs and agencies involved in other methods of snow control such as issues with causeways and planning of highways. There is contact information for each of the programs and agencies.

Memorandum of understanding. (n.d.). Living Snow Fence Partnership Program. 13 May 2009 Retrieved from http://www.forestry.iastate.edu/publications/MOUsnowfence.pdf

Summary: This document outlines the plan for the Living Snow Fence Partnership Program that was proposed several years ago. This plan involves the US Department of Agriculture – Farm Service Agency, the Continuous Conservation Reserve Program, the Minnesota Department of Transportation, the Minnesota Association of Soil and Water Conservation Districts, and the US Department of Agriculture – Natural Resources Conservation Service. The document lists benefits of living snow fences, the logistics of the proposed program, parties involved, the goals of the program and the roles each agency will perform.

New York State Department of Transportation, Vegetation and Environmental Programs Section, Office of Transportation Maintenance. (2008, Dec.). Green and Blue Highways Initiative: Report for State Fiscal Year 2007-8. 18 May 2009 Retrieved from https://www.nysdot.gov/divisions/ operating/oom/transportation-maintenance/repository/ Green and Blue Highways Report%202007-8-small.pdf

Summary: This report describes a project undertaken in New York State to improve Green and Blue Highways by improving vegetation along the roadways. These improvements included planting living snow fences.

Summary of SHRP research and economic benefits of snow and ice control. (1997, Dec.). Road Savers, U.S. Department of Transportation, Federal Highway Administration.

Abstract: In 1995, a project was initiated to assess the costs versus benefits of the Strategic Highway Research Program (SHRP). Information was collected from State and local highway agencies on their experiences with the SHRP products, and this information was used as the basis for an economic analysis of the costs and benefits of the program and its products.
This report summarizes the preliminary findings of an economic analysis conducted by the Texas Transportation Institute. It also describes the snow and ice control technologies developed under SHRP and the experiences of highway agencies that have used them. In addition, it summarizes the objectives of the research conducted under SHRP on snow and ice control, and outlines the work by the Federal Highway Administration to refine the products and encourage their adoption.

Tabler, R.D. (1973). Snow fences improve highway safety. Public Works 104(8), 74-75. Retreived from Scopus. Elsevier. 14 May 2009 http://www.scopus.com/

Abstract: Innovations in fence design and performance of the new fence systems in southwest Wyoming are described. The results have led the Wyoming Highway Department to use the methods and criteria to design an additional 40,000 feet of snow fence for second-priority sites, including those where poor visibility, rather than snow accumulation, is the principal problem.
USDA Conservation Reserve Program. (n.d.). Living snow fence [brochure]. Iowa.

Summary: This brochure outlines how landowners can apply for the cost-share living snow fence program which is part of the Conservation Reserve Program of the USDA. Purposes of LSF and a design example are given as well.

Windbreak technology for wild blueberry fields. (1996). Department of Agriculture and Aquaculture, New Brunswick Government. 19 May 2009 Retrieved from http://www.gnb.ca/0171/10/0171100001-e.asp

Summary: This fact sheet describes how to design a windbreak for blueberry fields. It discusses how the windbreak is useful in trapping snow to reduce damage to the blueberry plants; and there is a chart of trees and their characteristics that can be used in the suggested windbreaks. While this is not directly related to roads, it has useful information on how New Brunswick has developed windbreaks.

Wyatt. G.J. (1999). CRP snow fence (preventing snow drifting). Successful Farming. 97(3), 36. ProQuest Research Library. ProQuest. Syracuse University, Syracuse, NY. 13 May 2009 Retrieved from http://proquest.umi.com/

Abstract: Living snow fences, the planting of shrubs and trees specifically designed and planted in fields that will trip the snow before it can form drifts on roadways, are discussed.

Research

This category only contains a few articles, but they center around scientific research on windbreaks and living snow fences. Aspects such as the optical porosity of plants used, the aerodynamic structure of a windbreak, and wind speed are discussed.

Loeffler, A.E., A.M. Gordon, and T.J. Gillespie. (1992). Optical porosity and windspeed reduction by coniferous windbreaks in southern Ontario. Agroforestry Systems 17, 119 133. Retrieved from Scopus. Elsevier. Syracuse University, Syracuse, NY. 13 May 2009 http://www.scopus.com/

Abstract: Relative windspeed reduction was measured behind nine relatively narrow, homogeneous windbreaks in southern Ontario, Canada to assess whether any characteristics of the windspeed reduction curve could be predicted from optical porosity. The latter was determined for each windbreak using high contrast black and white photographic silhouettes on a computer digitizing system. Minimum windspeeds behind the windbreaks ranged from 29 to 71% of open windspeed; these minima were located 2 to 6 multiples of windbreak height away from the windbreak. Optical porosities of the bottom half of the windbreak ranged from 0 to 31%. Multiple regression of the shelter parameters (location and value of minimum relative windspeed) on the independent variables (optical porosity, open windspeed, surface roughness, approaching wind direction relative to the windbreak, average tree diameter and average tree spacing) showed that the minimum relative windspeed could be predicted from the optical porosity of the bottom half of the windbreak. The results suggest that optical porosity can be used to predict minimum relative windspeeds and may therefore be useful as a guide in the field evaluation of windbreaks.

Nixon, W.A., M. Davison, and G. Kochumman. (2006). Living snow fences. Iowa Highway Research Board Project Technical Report #460. University of Iowa. 12 May 2009 Retrieved from http://publications.iowa.gov/4871/1/tr460.pdf

Abstract: Blowing snow can cause significant problems for mobility and safety during winter weather in three distinct ways. It may drift onto the road, thus requiring almost continuous plowing while the wind is blowing (which may occur when a given winter storm is over). Snow may drift onto wet pavement (perhaps caused by ice control chemicals) and dilute out the chemicals on the road, creating ice on the road. And sufficient blowing snow can cause a major deterioration in visibility on the road, a factor which has been shown to be significant in winter crashes.
The problem of blowing snow can be very effectively addressed by creating a snow storage device upwind of the road that requires protection from snow drifting. Typically, these storage devices are fences. Extensive design guidance exists for the required height and placement of such fences for a given annual snowfall and given local topography. However, the design information on the placement of LSF is less complete. The purpose of this report is to present the results of three seasons of study on using standing corn as snow fences. In addition, the experience of using switch grass as a snow storage medium is also presented. On the basis of these experimental data, a design

guide has been developed that makes use of the somewhat unique snow storage characteristics of standing corn snow fences. The results of the field tests on using standing corn showed that multiple rows of standing corn store snow rather differently than a traditional wooden snow fence. Specifically, while a traditional fence stores most of the snow downwind from the fence (and thus must be placed a significant distance upwind of the road to be protected, specifically at least 35 times the snow fence height) rows of standing corn store the majority of the snow within the rows. Results from the three winters of testing show that the standing corn snow fences can store as much snow within the rows of standing corn as a traditional fence of typical height for operation in Iowa (4 to 6 feet) can store. This finding is significant because it means that the snow fences can be placed at the edge of the farmer's field closest to the road, and still be effective. This is typically much more convenient for the farmer and thus may mean that more farmers would be willing to participate in a program that uses standing corn than in traditional programs.
On the basis of the experimental data, design guidance for the use of standing corn as a snow storage device in Iowa is given in the report. Specifically, it is recommended that if the fetch in a location to be protected is less than 5,000 feet, then 16 rows of standing corn should be used, at the edge of the field adjacent to the right of way. If the fetch is greater than 5,000 feet, then 24 rows of standing corn should be used. This is based on a row spacing of 22 inches. Further, it should be noted that these design recommendations are ONLY for the State of Iowa. Other states of course have different winter weather and without extensive further study, it cannot be said that these guidelines would be effective in other locations with other winter conditions.

Zhou, X.H., et.al. (2004). Three-dimensional aerodynamic structure of a tree shelterbelt: definition, characterization, and working models. Agroforestry Systems 63, 133-147. Retrieved from Scopus. Elsevier. Syracuse University, Syracuse, NY. 13 May 2009 http://www.scopus.com/

Abstract: In order to make recommendations to landowners with regard to the design and management of tree shelterbelts, it is necessary to understand and predict the wind flow patterns associated with shelterbelt structure. A structural description is a prerequisite for any prediction of wind flow. Optical porosity (percentage of open spaces on the side view of a shelterbelt) has been used as a structural descriptor of a shelterbelt; however, it is a 2-dimensional measure unable to fully represent the aerodynamic influence of a tree shelterbelt. Based on numerous studies observing the wind fields associated with shelterbelt structure, the overall aerodynamic structure of a tree shelterbelt in three dimensions is defined by its external structural characteristics (length, height, width, and cross-sectional shape) and by its internal structural components (amounts and arrangements of vegetative surface area and volume, and geometric shape of individual vegetative elements). In order to associate the defined structure with wind speed, turbulent stress, and pressure, it is characterized using two structural descriptors the spatial functions of vegetative surface area density (vegetative surface area per unit canopy volume) and cubic density (vegetative volume per unit canopy volume). For field estimation, the two structural descriptors are expressed in three dimensions using two working models in terms of 1- or 2- dimensional sub-functions capable of being defined with field measurements. This paper discusses the rationale behind the definition, characterization, and working models for the 3-dimensional aerodynamic structure of a tree shelterbelt.