USDA
NATURAL RESOURCES
CONSERVATION SERVICE

DELAWARE CONSERVATION
PRACTICE STANDARD

WINDBREAK/SHELTERBELT ESTABLISHMENT

CODE 380
(Reported by Feet)

DEFINITION

Linear plantings of single or multiple rows of trees or shrubs, or sets of linear plantings.

PURPOSE

This practice may be applied for one or more of the following purposes:

1. To provide shelter for structures, livestock, and recreational areas;
2. To improve air quality by providing living barriers to reduce airborne odors (including ammonia), particulates, and chemical drift;
3. To manage snow deposition;
4. To provide living noise screens;
5. To provide living visual screens and enhance aesthetics;
6. To delineate property and field boundaries;
7. To provide wildlife habitat, including travel corridors;
8. To increase carbon storage in biomass and soils.

CONDITIONS WHERE PRACTICE APPLIES

This practice may be applied on any areas where linear plantings of woody plants are desired and are suitable for the intended purpose.

Windbreaks/shelterbelts are generally not used solely for purposes of enhancing aesthetics or providing wildlife habitat. These are usually secondary purposes that may complement a primary purpose such as visual screening or providing shelter for livestock.

This practice does not apply to plantings that are intended to function primarily as field borders, hedgerows, or riparian forest buffers, for which other standards are applicable. (Refer to the conservation practice standards for Field Border, Code 386; Hedgerow Planting, Code 422; and Riparian Forest Buffer, Code 391.)

CONSIDERATIONS

Consider the time of year when wind protection is needed and the direction of the prevailing wind.

Assess site conditions including surrounding land uses, soils, residual herbicides (to the extent known), available moisture during the growing season, and existing vegetation on the site and in adjacent areas, including any noxious weeds that may be present. Selection of plants should favor species or varieties tolerant to herbicides used in the area.

Avoid selecting plant species or planting near existing species that may be alternate hosts to undesirable pests, or that may be considered invasive or undesirable. Species diversity, including use of native species, should be encouraged in order to minimize problems due to species-specific pests.

When selecting and purchasing plants, consider the length of time needed to achieve the desired purpose. Slow-growing species will take longer to reach the design height than fast-growing species. Seedlings will take longer than containerized or balled-and-burlapped stock.

Consider wildlife when selecting tree and shrub species. When planting around poultry houses, species that are highly attractive to birds are undesirable. In other locations, consider using plants that have multiple wildlife values such as those suited for nesting habitat, fruit, seeds,

Conservation practice standards are reviewed periodically and updated if needed. To obtain the current version of this standard, contact your local Natural Resources Conservation Service office or visit the electronic Field Office Technical Guide.

browse, and protective cover.

Around buildings and other structures, consider soil quality especially in terms of compaction and potential contamination with construction debris, gravel, and other fill material. Compaction and inorganic fill materials can severely hinder plant rooting and survival. Consider the need for deep tillage and the addition of soil amendments to improve soil quality.

Consider the need for supplemental watering or irrigation when establishing plantings, especially if containerized stock or balled-and-burlapped plants will be used. During summer months when air temperatures, evaporation rates, and evapotranspiration rates are high, plants generally need at least 1 inch of water per week from rainfall or irrigation sources. Sufficient moisture during the first five years is important for plant survival and overall plant health.

Consider the need for weed control within and between rows. Weed control is extremely important to the establishment and longevity of windbreaks. Consider using plastic landscape fabric, polyethylene sheeting (6 mil), and/or mulch as a weed barrier. Pre- and post-emergent herbicides or periodic mowing may also be needed where weed pressure is high. For windbreaks that will be maintained with mowing, consider that plant spacing will need to accommodate mowing equipment.

Consider access routes and the need to maintain space for future expansion when designing windbreaks near buildings. Take note of other constraints such as economic feasibility, regulatory or program requirements, the need for permits or approvals, and visual aspects.

Consider that establishing visual screens for animal production and waste facilities may result in fewer odor complaints by neighbors. Windbreaks for controlling odor and dust particles will be more effective as the amount and density of foliage increases. Multiple row plantings are preferable because they provide greater interception than single row plantings. Windbreaks planted near animal facilities may also provide water quality benefits by intercepting nutrients in surface and subsurface water.

Consider that a curving planting may provide a more pleasing appearance than one with straight rows or squared corners.

When designing windbreaks for poultry houses, consider any additional requirements of the individual poultry company and the need to work with the industry representative to develop a feasible plan.

Consider the direction of prevailing winds in summer and winter when designing windbreaks near buildings and livestock areas. Windbreaks that are intended to provide protection from winter winds should be planted more densely, while those that are intended for shade should be planted more loosely to allow air circulation during summer months.

This practice has the potential to affect National Register listed cultural resources or eligible (significant) cultural resources. These may include archeological, historic, or traditional cultural properties. Care should be taken to avoid adverse impacts to these resources. Follow NRCS state policy for considering cultural resources during planning.

CRITERIA

General Criteria Applicable to All Purposes

Selection of Plant Species - Plant species shall be selected based on the planned purpose(s) of the windbreak, preferences of the client, and conditions of the site. Do not use weak-wooded species close to buildings where broken limbs can cause damage.

Plant growth rates, shade tolerance, soil moisture requirements and tolerances, and other plant characteristics shall be considered when selecting species. Within a row, use only one species or select a mix of species that have similar growth forms and growth rates.

Select plant species that are native to Delaware or are introduced and are non-invasive (i.e., not likely to spread beyond the planted area and displace native species). Plantings consisting of two or more species shall be encouraged. For best results, use species and varieties with proven conservation traits. Refer to Table 3 for a selected list of tree and shrub species that can be used.

Types of Plant Materials - Vegetation may be established by using bare-root seedlings,

containerized stock, or balled-and-burlapped stock. Only viable, high quality planting stock shall be used. If using containerized materials, do not transplant hardwood stock more than 1¾ inches trunk caliper and pine stock more than 2½ inches trunk caliper. Smaller caliper plants are easier to transplant and usually have higher survival rates than larger caliper stock. Trunk caliper of nursery stock is measured at 6 inches above the soil surface if the plant's caliper is equal to or less than 4 inches, in accordance with American Nursery and Landscape Association standards.

Design and Layout - The location, layout, and density of the planting shall be planned to accomplish the purpose and function intended within a 20-year period, or sooner as necessary.

The maximum design height (H) for the windbreak shall be the expected height of the tallest row of trees or shrubs at age 20 for the site. If the windbreak is intended to provide shade, select trees that will develop wide crowns and sufficient height to shade the area.

Density is the solid portion of the barrier, i.e., the amount of leaves, branches, and trunks in the windbreak. The density of a windbreak is determined by the choice of species (especially evergreen vs. deciduous), the number of rows used, and the spacing of the plants between and within rows. Windbreaks shall be planned to meet density requirements when specified in this standard for specific purposes.

Do not plant trees or shrubs where they will interfere with structures, operation of agricultural equipment such as irrigation systems, and above or below ground utilities.

Where water erosion and/or runoff from melting snow is a concern, tree and shrub rows shall be oriented on or near the contour. Do not allow drainage of livestock waste from a confined livestock area to flow into the windbreak. Use supporting practices, such as diversions or filter strips, as needed to redirect or reduce runoff.

Spacing between and within rows shall be based on the needed growing space for plant type and species, the accommodation of maintenance equipment, and the desired characteristics of the stem(s), branches, and canopy as required for a specific purpose.

Use staggered spacing in multiple row plantings. Plant taller-growing trees or shrubs in center rows and medium or lower growing species in outer rows.

Access lanes or roads that cut through windbreaks shall be at an angle to prevailing winds to prevent funneling of wind. Avoid gaps through single-row barriers.

Setbacks for Poultry Houses - If the windbreak will be constructed around a poultry house, determine the location of access lanes needed for servicing the structure. Then use the following minimum setback distances in areas where access is required:

1. If access is required along the sidewalls, a minimum setback of 50 feet is needed;

2. The minimum setback distance from each end of a poultry house is 80 feet.

If the house does not have tunnel ventilation and has a south or west exposure, the minimum setback is 100 feet to provide for air movement.

If the minimum setback distances listed above are not available, work with the individual poultry company to develop a feasible plan.

Site Preparation and Planting - Site preparation and planting to establish vegetative cover shall be done at a time and manner to insure survival and growth of selected species. Provide supplemental moisture if and when necessary to assure early survival and establishment of selected species.

Use Figure 3 and Table 2 to determine the appropriate planting dates for the different types of plant materials.

All plant materials must be correctly handled before planting. In general, plant materials shall be planted as soon as possible after receiving them from the supplier. For bare-root seedlings, keep the roots moist at all times and keep the plants out of direct sunlight as much as possible.

The method of planting shall include hand or machine planting techniques suited to achieving proper depths and placement for the selected plant species.

Protect vegetation from unacceptable impacts due to pests, wildlife, livestock, or fire. Exclude livestock as needed to establish vegetative cover.

Control noxious weeds as required by state law.

Comply with applicable federal, state, and local laws and regulations during the installation, operation, and maintenance of this practice. Follow state and local ordinances regarding set backs and traffic visibility requirements.

Additional Criteria to Provide Shelter for Structures, Livestock, and Recreational Areas

Height, Density, and Orientation - For wind protection, the windbreak shall be oriented as close to perpendicular to the prevailing damaging wind as possible, and have a minimum density of 65 percent during the months when protection is needed. The area to be protected shall be located within a leeward (downwind) distance of 2–5H from the planting (see Figures 1 and 2), but at least 100 feet downwind in snow country to allow adequate space for snowdrifts to accumulate.

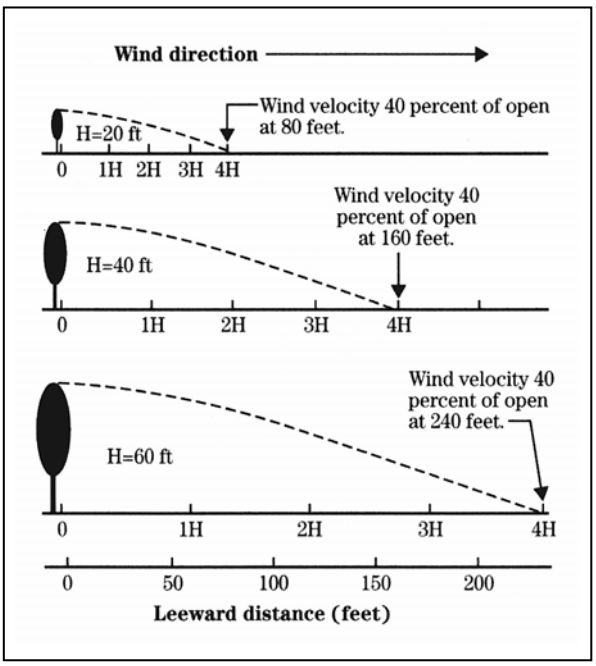
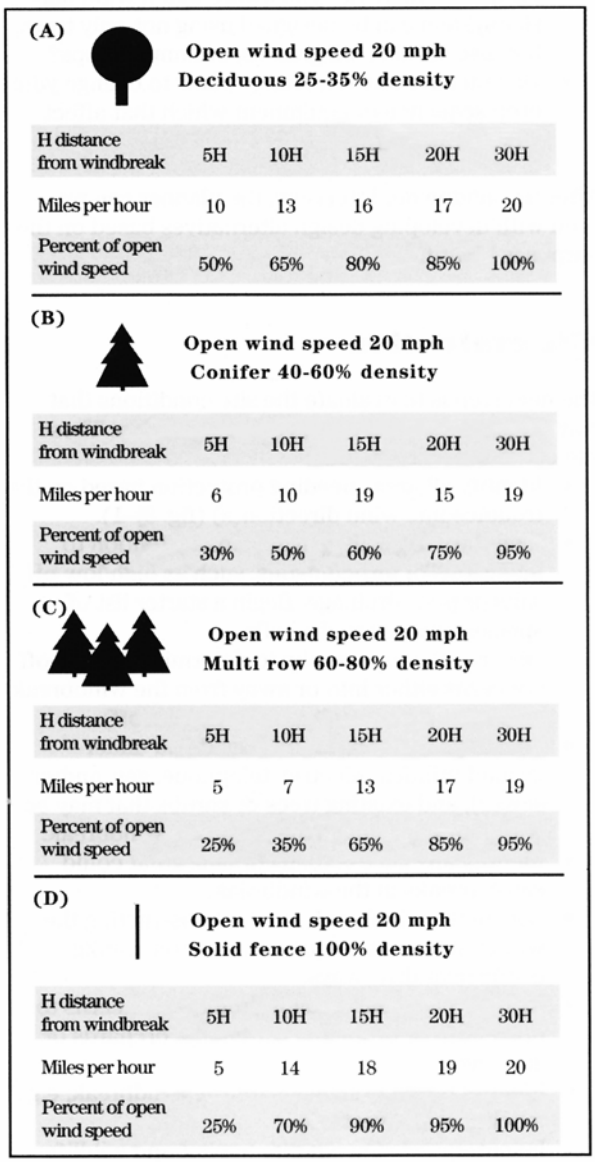


Figure 1. The leeward (downwind) distance of wind protection is proportional to the height of the barrier.

At least two rows of medium and/or high density plants (at least one row of which is trees) are usually needed to meet the minimum 65 percent density requirement. If year-round protection is needed, use at least two rows of evergreens, of which one row must be trees. For higher levels of protection, use at least three rows of trees and shrubs, with at least one row being evergreen trees. Use Tables 2 and 3 to determine appropriate spacing and species, respectively.

To allow for changes in wind direction, it may be necessary to design the windbreak to provide protection from multiple directions by using an L, U, or E shape. When orienting the windbreak, avoid placement that may cause future management problems.



(A) Open wind speed 20 mph Deciduous 25-35% density

H distance from windbreak	5H	10H	15H	20H	30H
Miles per hour	10	13	16	17	20
Percent of open wind speed	50%	65%	80%	85%	100%

(B) Open wind speed 20 mph Conifer 40-60% density

H distance from windbreak	5H	10H	15H	20H	30H
Miles per hour	6	10	19	15	19
Percent of open wind speed	30%	50%	60%	75%	95%

(C) Open wind speed 20 mph Multi row 60-80% density

H distance from windbreak	5H	10H	15H	20H	30H
Miles per hour	5	7	13	17	19
Percent of open wind speed	25%	35%	65%	85%	95%

(D) Open wind speed 20 mph Solid fence 100% density

H distance from windbreak	5H	10H	15H	20H	30H
Miles per hour	5	14	18	19	20
Percent of open wind speed	25%	70%	90%	95%	100%

Figure 2. The density of the barrier (type of planting, spacing, and number of rows) affects wind speed reduction leeward (downwind) of the windbreak.

Length - The length of the windbreak determines the amount of total area receiving protection. For best protection, the uninterrupted length of a

planting should exceed the height by at least 10:1. For example, if planned height of the planting is 30 feet, the windbreak needs to be at least 300 feet long to minimize the impact of air turbulence around the end of the planting. The windbreak should also extend at least 100 feet past the site being protected to account for air turbulence around the end of the planting.

Additional Criteria to Improve Air Quality by Reducing Airborne Odors, Particulates, and Chemical Drift

Windbreaks that are intended to intercept particulates and/or chemical drift shall consist of species that are tolerant of wind-borne particulates and herbicides from adjacent areas. Selection of species and length and location of plantings shall be determined based on the type of airborne materials to be reduced.

Plantings shall have a minimum density of 65 percent during the months when protection is needed. At least two rows of medium and/or high density plants (at least one row of which is trees) are usually needed to meet the minimum 65 percent density requirement. If year-round protection is needed, use at least two rows of evergreens, of which one row must be trees. For higher levels of protection, use at least three rows of trees and shrubs, with at least one row being evergreen trees. Use Tables 2 and 3 to determine appropriate spacing and species, respectively.

Particulates from Heavy Use Areas - To control airborne soil particulates ("dust") blowing from unvegetated heavy use areas (e.g., parking lots, horse exercise areas), locate windbreaks upwind of the source area to reduce air movement across the site. Locate windbreaks downwind of the source area if needed to intercept airborne particulates.

Sites will be protected within an area 10 times the design height (H) on the downwind side of the windbreak, and two times the design height (H) on the upwind side of the windbreak.

Odors and Chemical Drift - For control of odors and chemical drift, locate windbreaks both upwind and downwind of the source area.

To control odors, place plantings around the entire perimeter of the odor source if site conditions allow. Locate windbreaks upwind of the odor-producing area to disrupt airflow around it, increase turbulence in the air above it, and increase dilution of contaminants in the air, thus reducing odor.

Locate windbreaks downwind, between the odor source and sensitive area, so that foliage can intercept odors. Windbreaks for this purpose shall be extensive enough to account for wind direction changes at critical times.

To control chemical drift, locate windbreaks upwind of the chemical application area to reduce air movement and chemical drift. Locate windbreaks downwind of chemically treated areas to intercept drift. Plant species selections shall be compatible with the chemicals that are likely to be used.

Odor and Particulates from Poultry Houses - The following criteria apply to controlling odor and particulates vented from poultry house tunnel fans:

At least two rows of trees and/or shrubs shall be used in the planting. The first row (nearest the fans) shall be deciduous trees or shrubs, or a waxy-leaf evergreen shrub, such as an evergreen holly (*Ilex* sp.). The second row shall be evergreen or deciduous trees that are tolerant of ammonia and particulates vented from tunnel fans. 1- to 2-gallon container plants are recommended because they generally have better survival rates in fan impact areas than seedlings or balled-and-burlapped plants.

Species suitable for use with tunnel fans are:

1. Trees – 'Green Giant' Arborvitae, Eastern Red Cedar, Bald Cypress, Leyland Cypress, American Holly, 'Nellie Stevens' Holly, Honeylocust, Hybrid Poplar, Norway Spruce, 'Austree' Hybrid Willow, and 'Streamco' Purpleosier Willow;

2. Shrubs - Northern Bayberry, Japanese Holly, "Manhattan" Euonymus, and Southern Waxmyrtle.

See Table 3 for additional information concerning these species.

The closer the windbreak is positioned to the poultry house, the more effectively the odor, dust, and ammonia will be trapped and dispersed. Particulate trapping efficiencies may be

significantly reduced beyond 100 feet, depending on height of trees, wind speed/direction, and atmospheric conditions. Proximity of the plants for trapping efficiency must be balanced with plant survival, which decreases the closer the plants are to the tunnel fans.

For plant survival in fan impact areas, the nearest row of windbreak plantings shall be set back from the fans by a distance that is at least 10 times the exhaust fan diameter. (For example, if the tunnel ventilation fan has a diameter of 4 feet, then the first line of plants shall be planted at least 40 feet away.) In those cases where multiple fans are used in one location, this planting distance formula may be increased a minimum of 5 feet for each fan, depending on the number of fans that are likely to be running at the same time (e.g., bank of two 4-ft. diameter fans may need a 50-foot setback, four fans may need a 60-foot setback, etc.).

Where vehicle access is needed, the windbreak shall be placed a minimum of 50 feet from the sidewall and 80 feet from the end of the house.

If the minimum distance from the fans is not available, other barriers such as fencing, netting, tall grasses, or earthen berms may be needed to control particulates.

The use of drip irrigation shall be strongly encouraged to improve plant establishment and survival in tunnel fan impact areas. Spring planting of container stock is recommended, provided irrigation will be used.

Additional Criteria to Manage Snow Deposition

The windbreak shall be oriented as close to perpendicular to the snow-bearing wind as possible.

Distributing Snow - For even snow distribution across a field, the windbreak density during expected snow-producing months shall be from 25 to 50 percent. To meet this density requirement, use no more than one row of medium and/or high density trees, or two rows of low density trees and/or shrubs. (Windbreaks that exceed 50 percent density will trap snow, not distribute it.) Use Tables 2 and 3 to determine appropriate spacing and species, respectively.

Trapping Snow (Living Snow Fences) - For managing snow deposition, the minimum barrier density shall be at least 50 percent during expected snow-producing months. At least two rows of medium and/or high density plants (trees and/or shrubs) are usually needed to reduce wind velocities sufficiently for snow to accumulate. For higher levels of protection, use at least three rows of trees and shrubs, with at least one row being evergreen trees. Use Tables 2 and 3 to determine appropriate spacing and species, respectively.

Living snow fences shall be located so that snow deposition will not pose a health or safety problem or obstruct human, livestock, or vehicular traffic. Snow will be heavily deposited downwind within 100 to 200 feet from the planting. Be sure that roads or buildings are not located in this zone.

Additional Criteria to Provide Noise Screens

Noise screens shall have a minimum density of 65 percent during the months when noise abatement is needed, and shall be as close to and as tall as the noise source as practicable. The length of the noise screen shall be twice as long as the distance from the noise source to the receiver.

At least two rows of medium and/or high density plants (at least one row of which is trees) are usually needed to meet the minimum 65 percent density requirement. If year-round protection is needed, use at least two rows of evergreens, of which one row must be trees. For higher levels of protection, use at least three rows of trees and shrubs, with at least one row being evergreen trees. Plant as close together as practical to form a tight barrier. Use Tables 2 and 3 to determine appropriate spacing and species, respectively.

For high-speed traffic noise, the barrier shall not be less than 65 feet wide. For moderate speed traffic noise, the barrier width shall not be less than 20 feet wide. Species selected for traffic noise screens shall be tolerant of noxious emissions, sand and gravel depositions, and salt spray from traffic areas.

Additional Criteria to Provide Visual Screens

Visual screens shall be located as close to the observer as possible with a density, height, and width to sufficiently block the view.

One row of trees may be sufficient to provide an acceptable visual screen. If year-round protection is needed, use at least one row of evergreen trees. Refer to Table 2 to determine appropriate spacing.

Additional Criteria to Enhance Aesthetics

To enhance aesthetics, use evergreen species or species with features such as showy flowers, brilliant fall foliage, or persistent colorful fruits. Height, length, location, and number of rows shall be determined based on the primary purpose of the practice. Use Table 2 to determine appropriate spacing, based on primary purpose.

Additional Criteria for Providing Wildlife Habitat, including Travel Corridors

To enhance wildlife habitat, select trees and/or shrubs that will also provide food, nesting cover, and/or protective cover for the individual wildlife species or groups of desired species. Use locally native plant species when feasible.

Windbreaks that will serve as travel corridors shall be at least 50 feet wide and shall be used to connect two or more habitat areas (which are each at least 500 feet wide).

Height, length, location, and number of rows shall be determined based on the primary purpose of the practice. Use Tables 2 and 3 to determine appropriate spacing and plant species, respectively. For additional information concerning the wildlife value of various native tree and shrub species, refer to the Delaware conservation practice standard for Conservation Cover, Code 327.

Additional Criteria for Increasing Carbon Storage in Biomass and Soils

Carbon sequestration (storage) is the process through which carbon dioxide (CO_2) from the atmosphere is absorbed by plants and converted during photosynthesis into plant material. Carbon is stored in biomass (tree trunks, branches, foliage, and roots) and in soils (as leaf litter and other plant debris). Carbon sequestration rates vary by plant species, age, soil type, and climatic conditions.

Select appropriate species and stocking rates for site conditions and maximize the width and length of the windbreak to fit the site. Use fast-growing species (see Table 3 for growth rates) if rapid rates of carbon sequestration are desired. Prediction of carbon sequestration rates shall be made using current, approved carbon sequestration modeling technology.

Note: Specific cost-sharing programs or other funding sources may impose criteria in addition to, or more restrictive than, those specified in this standard.

PLANS AND SPECIFICATIONS

Plans and specifications for establishment of the windbreak shall be prepared in accordance with the previously listed criteria. Plans and specifications shall contain sufficient detail concerning site preparation and establishment to ensure successful installation of the practice. Documentation shall be in accordance with the section "Supporting Data and Documentation" in this standard.

In addition, follow the establishment recommendations provided in the Delaware Job Sheet for Trees and Shrubs or other applicable job sheet. The completed job sheet can serve as the planting plan for the windbreak.

OPERATION AND MAINTENANCE

The completed Job Sheet can serve as the operation and management plan as well as supporting documentation and shall be provided to the client. If necessary, additional management requirements can be developed on a site specific basis to assure performance of the practice as intended.

The following actions shall be carried out to insure that this practice functions as intended throughout its expected life:

1. Inspect trees and shrubs periodically and protect from adverse impacts including insects, diseases, fire, or damage from livestock and wildlife;

2. Control competitive grasses and weeds around plants by mowing, mulching, and/or chemical control until plants are well-established. Control all noxious weeds as required by state law;

3. Provide supplemental water as needed;

4. Replace dead trees and shrubs until the barrier is functional;

5. Thin or prune the barrier as needed to maintain its function;

6. For windbreaks that are planted to reduce particulates, build-up of particulates on leaves may threaten to smother and kill the plants. When feasible, periodically remove the accumulated particulate matter from the leaves by hosing the plants with water. Excessive accumulation of particulates may require installation of additional barriers such as fencing or netting to protect the plants.

SUPPORTING DATA AND DOCUMENTATION

The following is a list of the minimum data and documentation to be recorded in the case file:

1. Field location, extent of the windbreak or shelterbelt in length & width, conservation plan map or sketch showing the location and layout of the practice.

2. Assistance notes shall include dates of site visits, name or initials of the person who made the visit, specifics as to alternatives discussed, decisions made, and by whom;

3. Species selected for establishment, number of rows, spacing, total quantities needed, and planting dates;

4. Completed copy of the appropriate Job Sheet(s) or other specifications and management plans.

REFERENCES

1. Belt, S.V., M. van der Grinten, G. Malone, P. Patterson and R. Shockey, 2007. *Windbreak Plant Species for Odor Management around Poultry Production Facilities.* Maryland Plant Materials Technical Note No. 1. USDA-NRCS National Plant Materials Center, Beltsville, MD. 20p.

2. Brandle, James R., Xinhua Zhou, and Laurie Hodges, 2006. *How Windbreaks Work.* Publication EC1763, University of Nebraska, Lincoln Extension.

3. Kuhns, Mike, June, 1998. *Windbreak Benefits and Design.* Utah Forest Facts, NR/FF/005, Utah State University Extension.

4. Landowner Resource Center and University of Toronto Faculty of Forestry, 1995. *Designing and Caring for Windbreaks.* Extension Notes, Ontario, Canada.

5. Scott, James D., Jr., 2007. *VEB Tool-Kit: A Guide to Vegetative Buffers for Tunnel-Ventilated Poultry Houses.* Delmarva Poultry Industry, Inc., Georgetown, Delaware.

6. Tyndall, John, and Joe Coletti, 2000. *Air Quality and Shelterbelts: Odor Mitigation and Livestock Production, A Literature Review.* Forestry Department, Iowa State University, Ames, Iowa.

7. USDA, Natural Resources Conservation Service, July 1996. *Agroforestry for Farms and Ranches.* Agroforestry Technical Note No. 1.

8. USDA, Natural Resources Conservation Service. *Conservation Practice Standards.* Delaware Field Office Technical Guide, Section IV.

9. USDA, Natural Resources Conservation Service. *CORE4 Conservation Practices.* Chapter 3j: Windbreak/Shelterbelt.

10. Wight, Bruce, and Kimberly Stuhr, March, 2002. *Windbreaks: An Agroforestry Practice.* USDA, National Agroforestry Center, Agroforestry Note - 25.

FIGURE 3: USDA Plant Hardiness Zones for Delaware

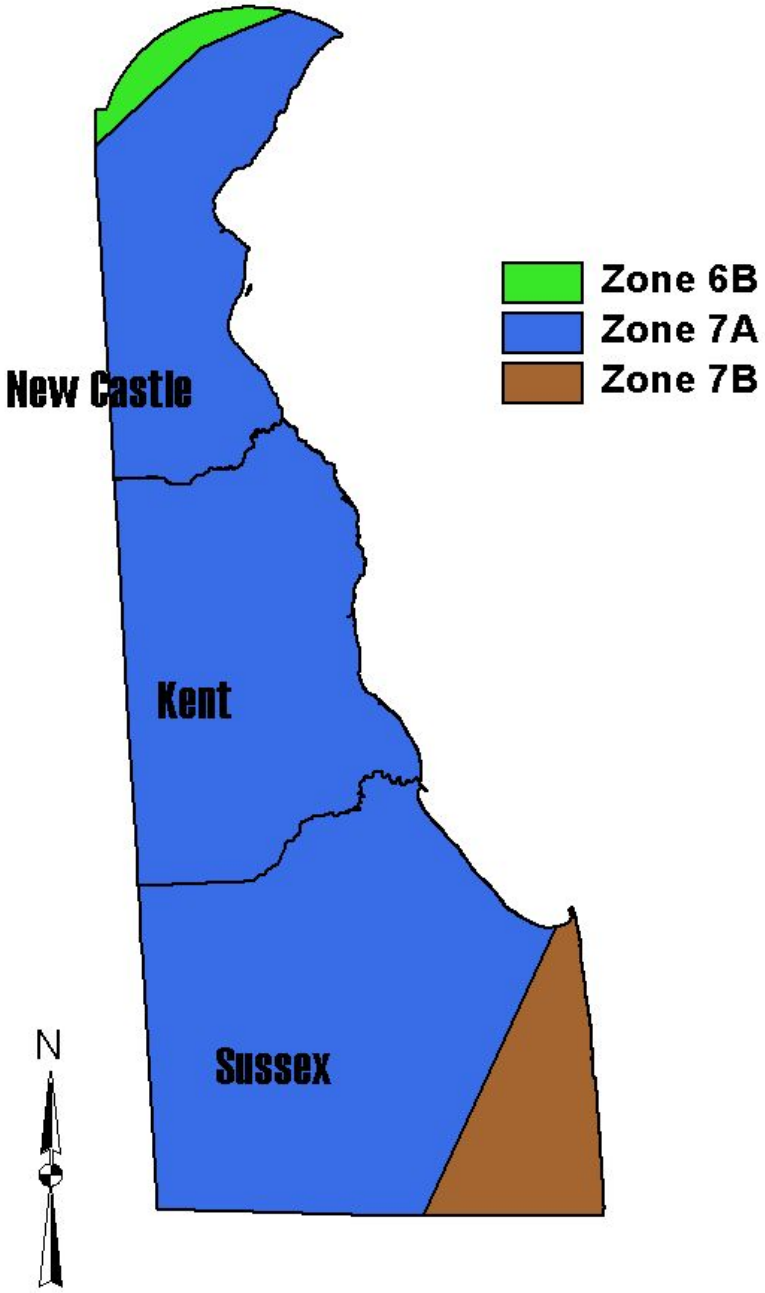


TABLE 1: Recommended Planting Dates in Delaware [1/]		
Type of Plant Material	**Plant Hardiness Zones**	
	6b	**7a and 7b**
Bare-Root Plants [2/]	Mar 1 to May 15 May 16 to Jun 30*	Feb 15 to Apr 30 May 1 to Jun 30*
Containerized Stock; Balled-and-Burlapped Stock	Mar 1 to May 15 May 16 to Jun 30* Sep 15 to Nov 30*✦	Feb 15 to Apr 30 May 1 to Jun 30* Oct 1 to Dec 15*✦

TABLE 1 NOTES:

1. The planting dates listed are averages for each zone. These dates may require adjustment to reflect local conditions, especially near the boundaries of the zones.

2. When planted during the growing season, most of these materials must be purchased and kept in a dormant condition until planting.

* Additional planting dates during which supplemental watering may be needed to ensure plant establishment.

✦ Frequent freezing and thawing of wet soils may result in frost-heaving of materials planted in late fall, if plants have not sufficiently rooted in place. Large containerized and balled-and-burlapped stock may be planted into the winter months as long as the ground is not frozen and soil moisture is adequate.

TABLE 2: Recommended Spacing Within and Between Rows [1/]			
Plant Type	**Spacing (feet) Within Rows:**		**Spacing (feet) Between Rows:**
	Single Row	*Multiple Rows*	
Small Shrubs (4 – 12 feet tall)	3 - 5	4 - 6	10 - 15
Large Shrubs and Small Deciduous Trees (12 – 30 feet tall)	6 - 8	8 - 10	10 - 20
Large Deciduous Trees (more than 30 feet tall)	10 - 12	12 - 14	15 - 20
Evergreen Trees (columnar form)	6 - 8	8 - 10	10 - 20
Evergreen Trees (conical and broad forms)	8 - 10	10 - 14	15 - 20

TABLE 2 NOTE:

1. Use spacings at or near the lower end of the range to create a dense barrier in a shorter period of time. Spacing between rows shall be at least four feet wider than the mechanized maintenance equipment used, and may be increased beyond what is shown in this table to accommodate the equipment.

TABLE 3: Selected List of Trees and Shrubs for Windbreak/Shelterbelt Plantings

Plant Names	Plant Hardiness Zones [1/]	Geographic Distribution in Delaware [1/]	Delaware Native Species	Soil Drainage Class [2/]	Height at 20 Years	Growth Rate [3/]	Density [4/] - Summer	Density - Winter	Remarks
DECIDUOUS TREES									
ASH, GREEN *Fraxinus pennsylvanica*	All	Statewide.	Yes	SP -P	35 ft.	Moderate	Medium	Low	Naturally occurring on streambanks and floodplains.
ASH, WHITE *Fraxinus americana*	All	Statewide.	Yes	W - SP	35 ft.	Moderate	Medium	Low	Attractive fall color (yellow to maroon).
ASPEN, QUAKING *Populus tremuloides*	6b	Higher elevations in the Piedmont.	Yes	W - SP	40 ft.	Fast	Low	Very Low	Very fast-growing; relatively short-lived tree. White bark and brilliant fall color. Good for visual screening and noise abatement. Use in one row, and add one or more other rows of slower-growing species. Has aggressive roots—keep away from structures, sewers, and tile lines.
BIRCH, RIVER *Betula nigra*	All	Mostly Coastal Plain; Piedmont, Ridge & Valley at lower elevations.	Yes	W - P	30 ft.	Fast	Low	Very Low	Naturally occurring on streambanks and floodplains. Unique peeling reddish bark. Attractive for landscaping.
BLACKGUM *Nyssa sylvatica*	All	Statewide.	Yes	W - P	30 ft.	Moderate	Medium	Low	Foliage turns bright red in early fall.
CYPRESS, BALD *Taxodium distichum*	All	Coast Plain.	Yes	MW - P	30 ft.	Fast	Medium to High	Low	Naturally occurring on streambanks and in swamps.
HONEYLOCUST *Gleditsia triacanthos* var. *inermis*	All	Statewide.	Yes	W - SP	40 ft.	Fast	Low to Medium	Very Low	Proven effective for odor control (passive ammonia absorption). Can be planted near poultry house tunnel fans.
MAPLE, RED *Acer rubrum*	All	Statewide.	Yes	W - P	35 ft.	Fast	Medium	Low	Red fall color and blooms.

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DECIDUOUS TREES (continued)									
OAK, PIN *Quercus palustris*	All	Statewide.	Yes	MW - P	35 ft.	Fast	Medium	Low	Bronze or red fall foliage. Widely planted as an ornamental. Produces small acorns.
OAK, NORTHERN RED *Quercus rubra*	All	Mostly Piedmont; uncommon on Coastal Plain.	Yes	W - SP	35 ft.	Fast	Medium	Low	Excellent red fall color. Tolerates urban conditions; perhaps the fastest-growing oak for landscapes.
OAK, SAWTOOTH *Quercus acutissima*	All	Introduced; not native to U.S.	No	W - SP	60 ft.	Fast	Medium	Low	Native to eastern Asia. Good shade tree. Tolerates adverse conditions.
OAK, SOUTHERN RED *Quercus falcata*	7a, 7b	Mostly Coastal Plain; infrequent elsewhere.	Yes	W - SP	35 ft.	Slow	Medium	Low	Excellent red fall color. Tolerates poor, dry soil.
OAK, SWAMP WHITE *Quercus bicolor*	All	Mostly Coastal Plain; infrequent elsewhere.	Yes	SP - P	30 ft.	Fast	Medium	Low	Good choice for wet sites. Requires acid soils.
OAK, WHITE *Quercus alba*	All	Statewide.	Yes	W - SP	35 ft.	Slow	Medium	Low	Variable fall color, stately tree.
OAK, WILLOW *Quercus phellos*	All	Mostly Coastal Plain; infrequent elsewhere.	Yes	MW - P	30 ft.	Fast	Medium	Low	Frequently used as an ornamental planting. Produces small acorns. Red fall color.
POPLAR, HYBRID *Populus deltoides x nigra* (var. 'Spike')	All	Introduced; hybrid of native U.S. and European species.	No	MW - SP	40 ft.	Fast	Medium	Low	Sterile hybrid. Proven effective for odor control (passive ammonia absorption). Can be planted near poultry house tunnel fans.

TABLE 3: Selected List of Trees and Shrubs for Windbreak/Shelterbelt Plantings

Plant Names	Plant Hardiness Zones [1/]	Geographic Distribution in Delaware [1/]	Delaware Native Species	Soil Drainage Class [2/]	Height at 20 Years	Growth Rate [3/]	Density [4/] - Summer	Density - Winter	Remarks
DECIDUOUS TREES (continued)									
POPLAR, TULIP *Liriodendron tulipifera*	All	Statewide.	Yes	W - SP	40 ft.	Fast	Medium	Low	Flowers produce abundant nectar, much used by bees. Dropped flowers and fruits can be messy. Tends to be weak-wooded, not recommended near buildings.
SWEETGUM *Liquidambar styraciflua*	All	Mostly Coastal Plain; infrequent elsewhere.	Yes	MW - P	40 ft.	Fast	Medium	Low	Excellent yellow-red fall color. Widely planted as an ornamental. Fallen seed heads are a nuisance on lawns. Fruitless types are available.
WILLOW, 'AUSTREE' HYBRID *Salix matsudana x alba*	All	Introduced; hybrid of Chinese and European species.	No	W - P	60 ft.	Very Fast	Medium to High	Low	Sterile hybrid. Due to its extremely fast growth (>3 ft/yr), can provide visual screen in 1 – 2 years. Proven effective for odor control (passive ammonia absorption). Can be planted near poultry house tunnel fans.
WILLOW, PURPLEOSIER 'STREAMCO' *Salix purpurea*	All	Introduced from Europe.	No	MW - P	20 ft.	Fast	Medium to High	Low	Non-invasive shrub. 'Streamco' is a male clone, does not root sucker, and does not spread readily beyond the planting site. Proven effective for odor control (passive ammonia absorption). Can be planted near poultry house tunnel fans.
EVERGREEN TREES									
ARBORVITAE *Thuja occidentalis*	All	Mostly Piedmont.	Yes	W - P	25 ft.	Slow	Very High	Very High	Frequently planted statewide as an ornamental. Prefers moist, well-drained soil, but tolerates a wide range of conditions. Prone to bagworms. Can be planted near poultry house tunnel fans.
ARBORVITAE, 'GREEN GIANT' *Thuja plicata x standishii*	All	Hybrid of Western U.S. and Japanese species.	No	W - MW	40 ft.	Fast	Very High	Very High	Prefers well-drained soil, but tolerates a wide range of conditions. No serious pest or disease problems. Proven effective for odor control (passive ammonia absorption). Can be planted near poultry house tunnel fans.

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Plant Names	Plant Hardiness Zones [1/]	Geographic Distribution in Delaware [1/]	Delaware Native Species	Soil Drainage Class [2/]	Height at 20 Years	Growth Rate [3/]	Density [4/] - Summer	Density - Winter	Remarks
EVERGREEN TREES (continued)									
CEDAR, EASTERN RED *Juniperus virginiana*	All	Mostly Piedmont.	Yes	W - SP	20 ft.	Moderate	Very High	Very High	Should not be planted near apple orchards; alternate host of cedar-apple rust. Proven effective for odor control (passive ammonia absorption). Can be planted near poultry house tunnel fans.
CYPRESS, LEYLAND *X Cupressocyparis leylandii*	All	Introduced; not native to U.S.	No	W - SP	40 ft.	Very Fast	Very High	Very High	This is a hybrid of *Cupressus macrocarpa* and *Chamaecyparis nootkatensis*. Adaptable to adverse sites; growth is best on good sites. Prone to bagworms, canker, and windthrow. Use in multiple-row plantings to minimize windthrow. Proven effective for odor control (passive ammonia absorption). Can be planted near poultry house tunnel fans. 'Green Giant' arborvitae is the preferred alternative to Leyland cypress.
FIR, DOUGLAS *Pseudotsuga menziesii*	6b	Introduced; native to Western U.S.	No	W - MW	40 ft.	Moderate	Medium	Medium	Prefers deep, moist, well-drained soils. Often planted for Christmas trees.
HOLLY, AMERICAN *Ilex opaca*	All	Mostly Coastal Plain.	Yes	W - P	20 ft.	Slow	High	High	Need male and female plants for fruit production. Shade tolerant. Can be planted near poultry house tunnel fans, but is very slow-growing. May be suitable for use in Row 1 to reduce wind velocity from fans, but should be backed by a fine-leaved evergreen to trap particulates. Proven effective for odor control (passive ammonia absorption).

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Plant Names	Plant Hardiness Zones [1/]	Geographic Distribution in Delaware [1/]	Delaware Native Species	Soil Drainage Class [2/]	Height at 20 Years	Growth Rate [3/]	Density [4/] - Summer	Density - Winter	Remarks
JUNIPER, CHINESE *Juniperus chinensis*	All	Introduced; not native to U.S.	No	W - SP	12 ft.	Fast	High	High	Height varies with cultivar. Cultivars with similar shapes & heights include 'Hetzii', 'Hetzii columnaris', 'Pyramidalis', 'Fairview', 'Keteleeri', 'Mountbatten', 'Spartan', 'Torulosa' (Hollywood juniper), and 'Robusta Green'. In cool wet springs, Chinese Juniper is susceptible to phomopsis and kabatina blights which can cause severe damage.
PINE, AUSTRIAN *Pinus nigra*	All	Introduced; not native to U.S.	No	E - P	35 ft.	Moderate	Low to Medium	Low to Medium	Frequently planted statewide as an ornamental. Prefers moist, well-drained soil, but tolerates a wide range of conditions. Withstands dryness better than other pines. Fairly salt tolerant.
PINE, LOBLOLLY *Pinus taeda*	All	Mostly Coastal Plain.	Yes	MW - P	45 ft.	Fast	Low to Medium	Low to Medium	Self-prunes lower limbs, so best suited in a multiple-row planting. Does not tolerate high levels of ammonia. Very poor results if planted near poultry house tunnel fans.
PINE, PITCH *Pinus rigida*	6b	Mostly Piedmont.	Yes	W - SP	30 ft.	Fast	Low to Medium	Low to Medium	Tolerant of dry, rocky, sandy soils. Mature trees are resistant to fire. Will reproduce from stump sprouts.
PINE, WHITE *Pinus strobus*	All	Mostly Piedmont.	Yes	W - MW	40 ft.	Fast	Low to Medium	Low to Medium	Frequently planted statewide as an ornamental. Does not tolerate high levels of ammonia. Very poor results if planted near poultry house tunnel fans.
SPRUCE, NORWAY *Picea abies*	All	Introduced; not native to U.S.	No	W - MW	35 ft.	Fast	High	High	Fast growth rate when young, slows down with age. Prefers moderately moist, well-drained soil. Proven effective for odor control (passive ammonia absorption). Can be planted near poultry house tunnel fans.
SPRUCE, WHITE *Picea glauca*	6b	Introduced; native to Northern U.S.	No	W - MW	30 ft.	Moderate	High	High	Good ornamental and shade tree. Tolerates heat, drought, and wind better than most spruces.

TABLE 3: Selected List of Trees and Shrubs for Windbreak/Shelterbelt Plantings

Plant Names	Plant Hardiness Zones [1/]	Geographic Distribution in Delaware [1/]	Delaware Native Species	Soil Drainage Class [2/]	Height at 20 Years	Growth Rate [3/]	Density [4/] - Summer	Density - Winter	Remarks
SHRUBS									
ABELIA, GLOSSY *Abelia x grandiflora*	7a, 7b	Coastal Plain	No	W - SP	6 ft.	Fast	High	High	No serious pests/diseases, may be burned back by a cold/hard winter. Semi-evergreen.
ARROWWOOD *Viburnum dentatum*	All	Statewide.	Yes	W - P	10 ft.	Fast	Medium	Low	Suckers freely. White flowers, bluish-black berries.
BAYBERRY, NORTHERN *Morella pensylvanica* (formerly *Myrica pensylvanica)*	All	Coastal Plain	Yes	W - SP	10 ft.	Moderate	Medium	Low	Need male and female plants for fruit production. Salt tolerant (0-20 ppt.) Suckers to form colonies. Can be planted near poultry house tunnel fans.
BUSH, HIGH TIDE (GROUNDSEL) *Baccharis halimifolia*	All	Coastal Plain	Yes	MW - P	10 ft.	Moderate	Medium	Low	Usually in brackish and coastal marshes, above MHW. Salinity 0-15 ppt. Has fluffy white seeds. Male flowers & female flowers on separate plants.
BUSH, HIGH TIDE (MARSH-ELDER) *Iva frutescens*	All	Coastal Plain	Yes	MW - P	10 ft.	Moderate	Medium	Low	Usually in brackish and coastal marshes, above MHW. Salinity 0-15 ppt.
DOGWOOD, REDOSIER *Cornus sericea*	All	Statewide; uncommon.	Yes	MW - P	8 ft.	Fast	Medium	Low	Attractive red stem color. White flowers and fruit.
DOGWOOD, SILKY *Cornus amomum*	All	Common on Coastal Plain & Piedmont.	Yes	MW - P	10 ft.	Fast	Medium	Low	Produces fruit at 3-5 years of age. White flowers with blue berries. Prefers some shade.
EUONYMUS, MANHATTAN Euonymus kiautschovicus 'Manhattan'	All	Statewide	No	W - SP	10 ft.	Moderate	High	High	Semi-evergreen foliage. Not as susceptible to scale as other euonymus; foliage often burns in winter; flowers attract bees and flies. Can be planted near poultry house tunnel fans.
HAZELNUT or AMERICAN FILBERT *Corylus americana*	All	Statewide	Yes	W - SP	10 ft.	Moderate	Medium	Low	Good for wildlife, ornamental, not many diseases/pests. Release by MOPMC. Monecious flowers (needs both male and female plants to produce nuts).

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SHRUBS (Continued)									
HOLLY, JAPANESE *Ilex crenata* (var. 'Steeds')	All	Introduced; not native to U.S.	No	MW - SP	8 ft.	Fast	High	High	Evergreen. Need male and female plants for fruit production. Tolerates partial shade. Excellent for high pollutant areas; can be planted near poultry house tunnel fans. Proven effective for odor control (passive ammonia absorption).
HOLLY, 'NELLIE STEVENS' *Ilex cornuta x aquifolium* (var. 'Nellie Stevens')	All	Introduced; not native to U.S.	No	MW - SP	15 ft.	Fast	High	High	Evergreen. Need male and female plants for fruit production. Tolerates partial shade. Can be planted near poultry house tunnel fans. Proven effective for odor control (passive ammonia absorption).
LESPEDEZA, SHRUB *Lespedeza bicolor*	All	Introduced; not native to U.S.	No	E - SP	8 ft.	Fast	Medium	Low	Perennial semi-woody legume. Cut back periodically to maintain dense, shrubby growth. May become weedy in some habitats and may displace desirable vegetation if not properly managed. Does not tolerate shade or wet soils.
WAXMYRTLE, SOUTHERN *Myrica cerifera*	7a, 7b	Coastal Plain.	Yes	W - SP	10 ft.	Moderate	Medium	Medium	Evergreen. Need male and female plants for fruit production. Salt tolerant (0-10 ppt). Can be planted near poultry house tunnel fans.

TABLE 3 NOTES:

1. The **Plant Hardiness Zones** designate where a species can be successfully planted in Delaware, while the **Geographic Distribution** describes where the species usually occurs under natural conditions.

2. **Soil Drainage Class** (refer to the county soil survey for further information):
   E - Excessively Drained; W - Well Drained; MW - Moderately Well Drained; SP - Somewhat Poorly Drained; P - Poorly Drained.

3. **Growth Rate:** Slow = less than 1 ft/year; Moderate = 1–2 ft/year; Fast = 2-3 ft/year; Very Fast = more than 3 ft/year.

4. **Density:** For an individual plant species, defined as the amount of space that is occupied by foliage, twigs, and branches, and can be estimated by the amount of light that can be seen through the plant. Low density – 25-35% of space occupied by plant material (with 65-75% open space through which air can travel); Medium density – 40-60% of space occupied by plant material; High density - 60-80% of space occupied by plant material; Very High – more than 80% of space occupied by plant material. The overall density of a windbreak is affected by the species selected, number of rows, and spacing between plants.