TWO DECADES OF PRAIRIE RESTORATION AT FERMILAB BATAVIA, ILLINOIS

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ABSTRACT: In the spring of 1975 seeds of 70 prairie species, hand-collected from remnant prairies within a 50-mile radius of Fermilab, were planted by Nisbet drill in a 3.9 ha (9.6 acres) of tilled agricultural soil within the Fermilab accelerator ring. Since that time, there have been 23 additional plantings both inside and outside the ring. The total area seeded to prairie is approximately 405 ha (1000 acres). During these past two decades a method of successional restoration has been developed. In this method, the seeds of early successional species having wide ecological tolerances, designated the **prairie matrix**, are drilled into recently cultivated ground. Within three years this prairie matrix provides an adequate fuel load capable of being burned. This initiates changes in the biological and physical structure of the soil necessary for the introduction and successful entry of higher successional prairie species having narrower ecological tolerances into the system. Continuous observations of these tracts have provided valuable information on large-scale prairie restoration, which in turn has led to: 1) the use of different and more efficient agricultural equipment; 2) changes in the methods of collecting, cleaning, and sowing of seed; 3) an increased use of both autumn and spring burns; 4) the development of new methods for the enrichment of plantings; and 5) studies on the possible use of mycorrhizal fungi inocula to hasten the establishment of higher successional species. In addition to the prairie restoration project, efforts are also being made to increase the species diversity of remnant wetlands and woods at Fermilab.

Key words: prairie, restoration, Fermilab

INTRODUCTION

During the autumn of 1974, approximately 181.2 kg (400 lb) of mixed prairie seeds (70 species) were hand-collected from remnant prairies found within 80.5 km (50 mi) of Fermilab. These were cleaned, and then stratified at approximately 5°C (40° F) for two months. In the first week of June 1975, these seeds were planted, using a Nesbit drill, into 3.9 ha (9.6 acres) of previously plowed and disked previously cultivated closely related soil types: Mundelein silt loam (Aquic Argiudoll), Wauconda silt loam (Udollic Ochraqualf), and Drummer silty clay loam (Typic Haplaquoll) located within the accelerator ring at Fermilab. During the first decade of restoration a total of 156 ha (385 acres), (mostly within the accelerator ring) were planted. Over this time there were a number of changes made in the methods used for ground cultivation, for planting, and for species enrichment of the prairie tracts subsequent to the initial planting (Betz 1986).

During the second decade an additional 239 ha (590 acres) of land were planted. In all, there have been 24 plantings (spring and autumn), bringing the total area to approximately 405 ha (1000 acres) both in and outside of the accelerator ring, (Table 1). Forty percent is within the accelerator ring and 60% outside.

Of the 656 species of vascular plants found at Fermilab, 147 are prairie species, or 22.4% of the total. At present 13 prairie species, such as, Indian paintbrush (*Castilleja coccinea*), New Jersey tea (*Ceanothus americanus*), eastern prairie fringed orchid (*Habenaria leucophaea*), rough white lettuce (*Prenanthes aspera*), and eared false foxglove (*Tomanthera auricula*) have not been found but eventually will be introduced.

There are 120 wet meadow species, or 18.3% of the total. At present there are 12 wet meadow species, such as, sweet flag (*Acorus clamus*) and marsh shield fern (*Dryopteris thelypteris pubescens*), which are not found at Fermilab but will be added.

The combined number of prairie and wet meadow species found in the 21 prairie plots varies from 16 in Plot 20, most recently planted, to 157 in Plot 6, which is relatively large with a variable topography. However, the richest in

Table 1. Size of prairie plots; when planted and number of species.

Plot #	When Planted	Hectares	Acres	# of Prairie & Wet Meadow Species
1	Spring 1975	3.6	9	89
2	Spring 1975	4.5	11	74
3	Spring 1977	11.7	29	83
4	Fall 1977	6.5	16	60
5	Fall 1978	4.5	11	52
6	Fall 1979	24.3	60	157
7	Spring 1981	6.9	17	52
8	Fall 1981	18.6	46	76
9	Fall 1982	22.7	56	97
10	Spring 1983	21.5	53	90
11	Spring 1984	13.0	32	110
12	Spring 1984	13.4	33	101
13	Spring 1985	19.0	47	122
14	Spring 1985	7.7	19	77
15	Spring 1986	20.2	50	84
16	Summer 1988	27.9	60	56
A-Tract	Summer 1989	30.4	75	21
17	Summer 1990	34.0	84	58
CA-2 Tract	Summer 1990	28.7	71	23
18	Spring 1992	4.0	10	26
A-Tract #2	Spring 1992	28.3	70	6
19	Summer 1993	22.3	55	12
20	Spring 1994	16.2	40	16
21	Spring 1995	14.2	35	—
Total		404.1	998	

terms of prairie species diversity is Plot 1 with 90 species (Table 1).

During the second decade of prairie restoration, efforts were also made to restore the degraded remnant wetland and woodland communities to their more natural states characteristic of the presettlement Illinois landscape. The number of native trees, shrubs, and herbaceous plants found in these woodlands is 196, or 30.0% of the total species present at Fermilab. One hundred and sixty-eight species of herbaceous non-native plants occur in these areas, or 25.6% of the total at the lab. In addition, the 25 species of woody exotics make up 3.8% of the total species found at Fermilab.

While herbicides are occasionally used to control non-native plants in a few places at Fermilab, such as, along roadsides and around buildings, they are not generally used in the restoration of the prairie. Rather these non-native plants are controlled and eliminated by the ecological competitiveness of the prairie species in areas repeatedly burned.

The Concept of Successional Restoration

"Successional restoration" is the method being used to restore the prairie at Fermilab on former agricultural fields. This involves an initial planting, using aggressive species that have wide ecological tolerances, which grow well on abandoned agricultural fields. Collectively, these species are designated as the prairie matrix (Betz 1986). The species used for this prairie matrix compete with and eventually eliminate most weedy species. They also provide an adequate fuel load capable of sustaining a fire within three years after a site has been initially planted. Associated changes in the biological and physical structure of the soil help prepare the way for the successful introduction of plants of the later successional species.

The species diversity is increased by introducing species with narrower ecological tolerances, characteristic of later successional stages, only after the species of the prairie matrix are well established

The species of the prairie matrix used originally included 25 species or approximately 10% of the prairie flora (Betz 1986). However, based on the experiences of the past decade (1986-1996), this number has been increased to 36 or about 24% of the original prairie flora (Table 2). Three species were removed from use in the prairie matrix and added to the second successional stage. They are prairie coreopsis (*Coreopsis palmata)*, Illinois tick trefoil (*Desmodium illinoense*), and purple coneflower (*Echinacea pallida).* Surprisingly, experience also showed that smooth beard tongue (*Penstemon calycosus*) and foxglove beard tongue (*P. digitalis*), originally included in the second stage, could be successfully used in the prairie matrix.

The number of species now included for the list of the second successional stage (Stage 2) is 48 (Table 3). Tentatively, a list of species designated as Stage 3 includes 16 species (Table 4), and 9 species are proposed for Stage 4 (Table 5).

Observations over the past 20 years have shown that it takes approximately 2 to 3 years for the prairie matrix to establish itself. Big bluestem grass (*Andropogon gerardii*) and Indian grass (*Sorghastrum nutans*) become dominant on mesic soil, and prairie cord grass (*Spartina pectinata)* dominated on wet soils. Switch grass (*Panicum virgatum*) is not a dominant, but has a minor presence in the developing prairie. The two other prominent prairie grasses, little bluestem (*Andropogon scoparius*) and prairie dropseed (*Sporobolus heterolepis*) appear to be species characteristic of the second or even the third stage.

It is interesting that the spontaneous introduction and subsequent dominance of asters (*Aster*) may be correlated with different successional stages. These stages and associated asters are as follows: a) weedy abandoned agricultural field—hairy aster (*A. pilosus*); b) Stage 1—Drummond's aster (*A. sagittifolius drummondii*); c) Stage 2—heath aster (*A. ericoides*) and New England aster (*A. novae-angliae*); d) Stage 3—sky-blue aster (*A. azureus*) and smooth blue aster (*A. laevis*).

With few exceptions, the sequence of species from Stage 1 to Stage 4 is similar to the sequence proposed by Peter Schramm (1990). However, there are differences in what constitutes a stage. Our Stage 1 is a combination of Schramm's Stage I (Initial Downgrow Weedy Stage) and Stage II (Intense Competitive, Stand Establishment Stage). Our Stage 2 is similar to Schramm's Stage III (Closeout Stage). Our Stage 3 and Stage 4 are combined into Schramm's Stage IV (Long-term Adjustment Stage).

METHODS

Harvesting Seed of the Prairie Matrix

Seed of the prairie matrix is harvested by use of a self-propelled combine. Approximately 8000 to 10,000 pounds of uncleaned seed are typically collected each year from tracts with earlier plantings of prairie matrix. In 1989 a record of over 13,000 lbs were collected. However, in some years it is necessary to harvest matrix seed from more recent tracts in order to collect seed for plants, such as Indian grass (*Sorghastrum nutans*), yellow cone flower (*Ratibida pinnata)*, and showy tick trefoil (*Desmodium canadense*) whose populations quickly decrease under competition in later stage plantings.

Table 2. Prairie species of the first stage.

Allium canadense (wild onion)
Allium cernuum (nodding wild onion)
Andropogon gerardii (big bluestem grass)
Aster sagittifolius drummondii (Drummond's aster)
Baptisia leucantha (white wild indigo)
Coreopsis tripteris (tall coreopsis)
Desmodium canadense (showy tick-trefoil)
Elymus canadensis (Canadian wild rye)
Helianthus mollis (downy sunflower)
Heliopsis helianthoides (false sunflower)
Lespedeza capitata (round-headed bush clover)
Monarda fistulosa (wild bergamot)
Panicum virginicum (switch grass)
Parthenium integrifolium (wild quinine)
Penstemon calycosus/digitalis (smooth/foxglove breard tongue)
Pycnanthemum virginianum (common mint)
Ratibida pinnata (yellow coneflower)
Rudbeckia hirta (black-eyed Susan)
Rudbeckia subtomentosa (sweet black-eyed Susan)
Senecio paurperculus balsamitae (balsam ragwort)
Silphium integrifolium (rosin weed)
Silphium lacinatum (compass plant)
Silphium terebinthinaceum (prairie dock)
Solidago gigantea (late-flowering goldenrod)
Solidago graminifolia (narrow-leaved grassleaved goldenrod)
Solidago gymnospermoides (wide-leaved grassleaved goldenrod)
Solidago juncea (early goldenrod)
Solidago nemoralis (gray goldenrod)
Solidago riddellii (Riddell's goldenrod)
Solidago rigida (stiff goldenrod)
Sorghastrum nutans (Indian grass)
Spartina pectinata (prairie cord grass)
Thalictrum dasycarpum (purple meadow rue)
Thalictrum revolution (waxy meadow rue)
Vernonia fasciculata (common ironweed)
Zizia aurea (golden Alexanders)

Table 3. Prairie species of the second stage (proposed).

Agalinis tenuifolia (slender false foxglove)
Andropogon scoparius (little bluestem)
Anemone canadensis (Canadian anemone)
Anemone cylindrica (thimbleweed)
Asclepias tuberosa (butterflyweed)
Asclepias sullivantii (prairie milkweed)
Aster novae-angliae (New England aster)
Aster ericoides (heath aster)
Cacalia plantaginea (Indian plantain)
Carex bicknellii (prairie sedge)
Cicuta maculata (water hemlock)
Comandra umbellata (false toadflax)
Coreopsis palmata (prairie coreopsis)
Desmodium illinoense (Illinois tick-trefoil)
Dodecatheon meadia (shooting stars)
Echinacea pallida (purple coneflower)
Eryngium yuccifolium (rattlesnake master)
Euphorbia corollata (flowering spurge)
Galium boreale (northern bedstraw)
Galium obtusum (wild madder)
Gentiana andrewsii (bottle gentian)
Gentiana flavida (yellow gentian)
Gentiana quinquefolia (stiff gentian)
Helianthus rigidus (prairie sunflower)
Krigia biflora (false dandelion)
Lathyrus palustris (marsh vetchling)
Liatris pycnostachya (prairie blazing star)
Liatris spicata (marsh blazing star)
Liatris aspera (rough blazing star)
Lobelia spicata (pale-spiked lobelia)
Oxypolis rigidior (cowbane)
Pedicularis canadensis (prairie betony)
Pedicularis lanceolata (marsh betony)
Petalostemum candidum (white prairie clover)
Petalostemum purpureum (purple prairie clover)
Phlox glaberrima interior (marsh phlox)
Phlox pilosa (prairie phlox)
Physostegia virginiana (false dragonhead)
Polytaenia nuttallii (prairie parsley)
Potentilla arguta (prairie cinquefoil)
Prenanthes aspera (rough white lettuce)
Prenanthes racemosa (glaucus white lettuce)
Psoralea tenuifolia (scurfy pea)
Salix humilis (prairie willow)
Sisyrichium albidum (blue eyed-grass)
Tradescantia ohiensis (common spiderwort)
Veronicastrum virginicum (Culver's root)
Vicia americana (American vetch)

The harvested uncleaned matrix seed is transferred mechanically to a truck and hauled to a large barn where it is mixed and spread out on the floor to a depth of about ten inches to dry. For a number of weeks thereafter, the seed periodically is turned over to enhance drying while also preventing the heat from reaching a kindling point and causing a fire. After drying, the seed is stored on the barn floor over winter and is used for sowing tracts in the late spring. The seed is not cleaned in any way and contains approximately one-third chaff.

Method of Soil Preparation

The plot to be planted is plowed and disked during the autumn of the previous year. If required, clumps of soil are broken up using a cultipacker with the tines down. This is followed by further disking. In the spring of the planting year a further disking is usually done just before planting in order to destroy most of the emerging weed flora which could inhibit the young matrix seedlings.

Table 4. Prairie plants of the third stage (proposed).

Amorpha canaescens (lead plant)
Asclepias hirtella (tall green milkweed)
Asclepias viridiflora (short green milkweed)
Aster azureus (sky-blue aster)
Aster laevis (smooth aster)
Baptisia leucophaea (cream wild indigo)
Bromus kalmii (Kalm's brome grass)
Chelone glabra (turtlehead)
Heuchera richardsonii grayana (alum root)
Lithospermum canescens (hoary puccoon)
Lysimachia quadriflora (narrow-leaved loosestrife)
Panicum leibergii (prairie panic grass)
Polygala senega (Seneca snakeroot)
Spiranthes magnicamporum (ladies' tresses orchid)
Sporobolus heterolepis (prairie dropseed)
Valeriana ciliata (common valerian)

Table 5. Prairie plants of the fourth stage (tentative).

Asclepias meadii (Mead's milkweed)
Cypripedium candidum (white ladies's slipper)
Gentiana puberulenta (prairie gentian)
Habenaria leucophaea (white fringed orchid)
Hypoxis hirsuta (yellow star grass)
Lilium philadelphicum andinum (prairie lily)
Oxalis violacea (purple wood sorrel)
Scutellaria parvula leonardii (small skullcap)
Viola pedatifida (prairie violet)

Method of Sowing

There have been a few changes in sowing of seed regime followed during this past decade. One of the modifications involved the use of a fertilizer buggy drawn by a tractor in order to spread uncleaned matrix seed onto prepared soil instead of using an all-terrain spreader as was previously done. Both types of machines are excellent for sowing seed, but it was more cost effective in the long run to purchase the buggy than to continually rent the all-terrain spreader each year at a time when it is in use by local farmers.

The release of the seed from the buggy is adjusted to give a maximum spread of arc and an optimum covering of the ground with seeds. This is about 27.7 kg/ha (30 lbs/acre). Afterwards a cultipacker with the tines up is usually used as a roller to ensure good seed-to-soil contact.

Since many of the matrix plants are warm season plants, sowing is usually done during the first weeks in June when the matrix seed will germinate quickly and the seedlings will grow well. However, matrix seed can be sown throughout the months of June and July and still give excellent results.

Mowing the First Year

Eurasian weeds that quickly develop in the newly seeded tracts are usually mowed once or twice during the first year or two to allow sunlight to penetrate down to the young matrix seedlings. This is accomplished using a rotary mower raised about 12 to 14 inches high. The tracts are mowed often enough so the thatch produced in the mowing does not smother the young seedlings.

ENRICHMENT OF THE PRAIRIE TRACTS

The matrix constitutes about 24% of the presettlement prairie species. However, in order to increase species diversity, it is necessary periodically to enrich the tracts with later successional species. Examples of species used include lead plant (Amorpha canescens), smooth aster (*Aster laevis*), prairie coreopsis (*Coreopsis palmata*), prairie blazing star (*Liatris pycnostachya*), purple prairie clover (*Petalostemum purpureum*), waxy meadow rue (*Thalictrum revolutum*), Culver's root (*Veronicastrum virginicum*), and golden Alexanders (*Zizia aurea*).

In addition, an effort is made to enrich the earlier plantings in which some matrix species are not well established. Species used include nodding wild onion (*Allium cernuum*), tall coreopsis (*Coreopsis tripteris*), round-headed bushclover (*Lespedeza capitata*), yellow cone flower (*Ratibida pinnata*), and prairie dock (*Silphium terebinthinaceum*).

Collection of Seed for Prairie Enrichment

Certain species of the matrix, as well as selected species of the second stage which have large developing populations at Fermilab prairie, are collected by hand. For that purpose the Roads and Grounds Department of Fermilab organizes and supervises two seed harvest days each year using volunteers. One is in late September and the other in late October. Among the species from which seed is collected are nodding wild onion (*Allium cernuum*), prairie coreopsis (*Coreopsis palmata*), showy tick trefoil (*Desmodium canadense*), wild quinine (*Parthenium integrifolium*), and sweet black-eyed Susan (*Rudbeckia hirta*).

Seeds of later successional stages are also hand-collected throughout the year from remnant prairies within a 50-mile radius of Fermilab. One such remnant is along a railroad right-of-way running through Fermilab. Species available by this means include shooting stars (*Dodecatheon meadia*), rattlesnake master (*Eryngium yuccifolium*), button blazing star (*Liatris aspera*), prairie blazing star (*L. pycnostachya*), marsh blazing star (*L. spicata*), prairie lily (*Lilium philadelicum andinum*), and Culver's root (*Veronicastrum virginicum*).

Seed is also obtained by exchange arrangements with many of the county forest preserve districts in the vicinity of Fermilab. Matrix seed collected at Fermilab is exchanged for seed to be used in enriching the Fermi plantings.

Some of the seeds collected are relatively clean and easily separated from one another when picked, and thus they do not require further cleaning. Examples are false toadflax (Comandra *richardsiana*), shooting stars (*Dodecatheon media*), prairie clovers (*Petalostemum spp.*), and prairie cinquefoil (*Potentilla arguta*).

All seeds are held under moist conditions throughout the winter months in an unheated barn. Legumes are first scarified using blocks of wood covered with emery paper, moistened, and then inoculated with a specific *Rhizobium* culture.

Since many prairie species produce seed that remain covered within their fruit coat, a converted soil shredder is used to break up these fruits in order to release the seeds. Finally, a mechanical cleaner is used to remove dried parts of stems, leaves, and flowers that are frequently mixed in with the harvested seeds.

Methods Used in Planting Enrichment Seed Mixes

Three methods of enrichment planting are regularly used: 1) drilling; 2) mechanical broadcast sowing; and 3) hand sowing.

1) Drilling. This method involves the planting of cleaned seeds into recently burned prairie tracts by use of a Nisbet drill. Drilling of the seed into the soil offers a better chance for seed to germinate and successfully establish seedlings. This method is used to enrich the older plantings with late successional species which are relatively uncommon and difficult to collect in large quantities.

In preparation for drilling, the cleaned seeds are distributed into seven different mixtures according to the type of habitat into which they are to be planted. These habitat mixtures are: 1) mesic prairie for use in older plantings; 2) mesic prairie for use in newer plantings); 3) dry prairie; 4) wet prairie); 5) marsh; 6) savanna; and 7) woods.

Because seeds vary in size, smoothness, and sometimes fluffiness, they are placed in separate compartments of the Nesbit drill. Species with smooth seeds, such as prairie cinquefoil (*Potentilla arguta*), Culver's root (Veronicastrum virginicum), and golden Alexanders (*Zizia aurea*), are placed in the smaller compartments; whereas, species with fluffy seeds, such as prairie Indian plantain (*Cacalia plantaginea*), rough blazing star (*Liatris aspera*), and early goldenrod (*Solidago juncea*), are placed in the larger compartments. The planting rate of the seeds in each compartment can be controlled by adjusting the size of the orifice at the bottom of each compartment and the rate of flow through the drill.

The tract to be planted is first burned either in autumn or early spring to remove the dried vegetation from the previous growing season. This enables the drill to more efficiently bury the seeds into the soil. Seeds are usually planted from a quarter- to a half-inch depth.

2) Mechanical Broadcast Sowing. This method of enrichment involves the use of a fertilizer buggy pulled by a tractor. Clean or uncleaned seed is dispersed onto burned or unburned prairie tracts during the nongrowing seasons (late autumn, winter, and early spring) or onto ground covered with snow. It is generally used to enrich more recent plantings that are missing some of the species of the matrix or other early successional species.

3) Hand Sowing. This method of enrichment is especially useful to plant seed from prairie species that bloom and ripen seed in spring and early summer. This includes, false toadflax (*Comandra richardsiana*), yellow stargrass (*Hypoxis hirsuta*), hairy puccoon (*Lithospermum canescens*), pale spiked lobelia (*Lobelia spicata*), prairie lousewort (*Pedicularis canadensis*), marsh phlox (*Phlox glaberrima*), prairie phlox (*P. pilosa*), and blue-eyed grass (*Sisyrinchium albidum*). Rather than store this seed for months before planting and have it undergo loss of viability, it is hand-sown immediately after collecting into localized areas designated as foci (sing. focus) that show richer arrays of species than generally found throughout a planting, .

Fire Management

Fire is necessary for the establishment and maintenance of prairie. There is absolutely no substitute for it. At Fermilab, most of the 24 planted prairie plots have been burned repeatedly during the past 20 years either in late autumn or early spring. Prairie burns are carried out by trained crews from Fermilab's Department of Roads and Grounds.

There is no set date for burning in the autumn, but it is usually during November or early December after most seed has ripened and been harvested from the plants. Burns may be conducted until weather conditions with low temperatures and high humidity prevent a vigorous fast moving fire. Since much of the dried vegetation is standing at this time, the burns are spotty leaving the landscape with partially blackened areas interspersed with standing unburned vegetation.

In spring, burning begins when weather conditions favor fires that move aggressively though the dried prairie vegetation. Usually this period is toward the end of February or beginning of March. Burning ends before the appearance of shoots and buds of early spring prairie plants. Such plants include nodding wild onion (Allium cernuum), white wild indigo (*Baptisia leucantha*), and golden Alexanders (*Zizia aurea*). Usually, the burn period ends about the middle of April. Because the winter snow flattens and compacts the dried vegetation, the spring burns are hotter and more vigorous than autumn burns. Spring burns produce a flat blackened landscape with little standing vegetation.

To facilitate burning, a group of the earliest plantings lying adjacent to each other, along with the adjoining marshes and woodlands, are designated as a single burn unit or tract. The burn unit is purposely isolated from surrounding areas by roads, creeks, and mowed fire breaks. More recently planted areas, in which the matrix species are still not well-established and dominant, are not grouped into burn units but are burned separately. A typical burn unit is approximately 200–300 acres.

The frequency with which the prairie tracts are burned varies with the age of the planting. The more recent plantings are usually burned annually for five or six years. This gives opportunity for the prairie matrix species to become established while the weedy vegetation is put under stress.

Older plantings are burned less often. Priority for burning these is given in this order: 1) tracts that have not been burned in the last two or three years and have accumu-

lated considerable amounts of fuel load; 2) tracts that contain substantial amounts of woody vegetation; and 3) tracts that are to be enriched using a Nisbet drill.

The frequency of burning is also dependent on wind direction. There are many laboratory buildings scattered throughout Fermilab. If the smoke and ash arising from a prairie fire should blow toward any of these buildings, this could interfere with the activities within those buildings. Because of this possibility, some tracts can only be burned when wind blows from the right direction. If the proper wind conditions are not present during the burn period, a tract is not burned. For this reason certain tracts may not be burned for two or more years in a row.

RESTORATION CHRONOLOGY

In autumn the tract that has been sowed during the previous spring with prairie matrix takes on the appearance of a weedy field with an assortment of annual and first-year biennials, such as ragweeds (*Ambrosia spp.*), thistles (*Cirsium spp.*), Queen Anne's lace (*Daucus carota*), smartweeds (*Polygonum spp.*), and Eurasian clovers (*Trifolium spp.*). However, a closer inspection of the soil surface under these weeds show young seedlings of big bluestem grass (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), showy tick trefoil (*Desmodium canadense*), wild bergamot (*Monarda fistulosa*), yellow cone flower (*Ratibida pinnata*), compass plant (*Silphium laciniatum*), and other species of the prairie matrix. Usually after two, or possibly three, growing seasons, a sufficient fuel load has accumulated which is capable of supporting a burn.

Within five years, coupled with annual burns, the prairie matrix usually dominates a large portion of the tract. The dominant grasses are big bluestem grass (*Andropogon gerardii*) and Indian grass (*Sorghastrum nutans*). In low spots prairie cord grass (*Spartina pectinata*) slowly is becoming common. Scattered throughout the tract are the various common prairie matrix forbs, such as, nodding wild onion (*Allium cernuum*), white wild indigo (*Baptisia leucantha*), tall coreopsis (*Coreopsis tripteris*), showy tick trefoil (*Desmodium canadense*), wild bergamot (*Monarda fistulosa*), common mountain mint (*Pycnanthemum virginianum*), yellow coneflower (*Ratibida pinnata*), black eyed Susan (*Rudbeckia hirta*), rosin weed (*Silphium integrifolium*), prairie compass plant (*S. laciniatum*), and prairie dock (*S. terebinthinaceum*).

Also present within this first stage tract are local spots with weedy vegetation representative of an earlier successional stage. Common species found in these weedy patches are Hungarian brome grass (Bromus *inermis*), reed canary grass (*Phalaris arundinacea*), Canadian thistle (*Cirsium arvense*), bull thistle (*C. vulgare*), and tall goldenrod (*Solidago altissima*). With the passage of time and the occurrence of annual fires, these local weedy spots slowly disappear as the aggressive plants of the prairie matrix invade. These invaders include big bluestem grass (*Andropogon gerardi*), Indian grass (*Sorghastrum nutans*), tall coreopsis (*Coreopsis tripteris*), yellow cone flower (*Ratibida pinnata*), and prairie goldenrod (*Solidago rigida*). It is interesting to observe the year-by-year disruption and contraction of swards of Hungarian brome grass (*Bromus inermis*) and reed canary grass (*Phalaris arundinacea*), and clones of tall goldenrod (*Solidago altissima*) and Canada thistle (*Cirsium arvense*) as the matrix species invade.

During the next five to ten years Indian grass (*Sorghastrum nutans*) some of the early forbs, such as, black-eyed Susan (*Rudbeckia hirta*) and showy tick trefoil (*Desmodium canadense*), decrease in number and survive primarily on the periphery of the tract. Switch grass (*Panicum virgatum*) is likewise relegated to a minor position and survives mostly in areas adjacent to wet areas. Both little bluestem (*Andropogon scoparius*) and prairie dropseed (*Sporobolus heterolepis*) are uncommon and local.

This leaves big bluestem (*Andropogon gerardii*) as the sole dominant grass throughout the developing prairie. The tract now has the appearance of a monoculture of this grass standing 2 m or more in height. However, throughout the tract new forbs of the prairie matrix are increasing their populations and becoming more evident, especially in foci. These forbs include: nodding wild onion (*Allium cernuum*), wild quinine (*Parthenium integrifolium*), common mountain mint (*Pycnanthemum virginianum*), sweet black-eyed Susan (*Rudbeckia subtomentosa*), and various species of goldenrod—grass-leaved sunflower (*Solidago gymnospermoides*), early goldenrod (*S. juncea*), gray goldenrod (*S. nemoralis*), Riddell's goldenrod (*S. riddellii*) and prairie goldenrod (*S. rigida*).

In addition to these first stage species, plant species belonging to the second stage are slowly beginning to make their appearance within foci. Examples of these species are heath aster (Aster *ericoides*), prairie sedge (*Carex bicknellii*), prairie coreopsis (*Coreopsis palmata*), shooting stars (*Dodecatheon meadia*), purple coneflower (*Echinacea pallida*), rattlesnake master (*Eryngium yuccifolium*), prairie blazing star (*Liatris pycnostachya*), marsh blazing star (*L. spicata*), pale-spiked lobelia (*Lobelia spicata*), prairie betony (*Pedicularis canadensis*), white prairie clover (*Petalostemum candidum*), and purple prairie clover (*P. purpureum*), marsh phlox (*Phlox glaberrima interior*), false dragonhead (*Physostegia virginiana*), and Culver's root (*Veronicastrum virginicum*).

From the tenth and to the fifteenth years, Stage 2 species within foci slowly increase their numbers. Isolated specimens of new species of the second stage begin to

appear for the first time. These include Indian plantain (*Cacalia tuberosa*), water hemlock (*Cicuta maculata*), Illinois tick trefoil (*Desmodium illinoense*), bottle gentian (*Gentiana andrewsii*), yellow gentian (*G. flavida*), cardinal flower (*Lobelia cardinalis*), cowbane (*Oxypolis rigidior*), prairie parsley (*Polytaenia nuttallii*), and glaucous white lettuce (*Prenanthes racemosa*).

Between the fifteenth and twentieth years Stage 2 species increase in numbers and begin to increase the size of the foci. New populations of these and other second stage species slowly begin to appear throughout the tract. The additional species of Stage 2 are (prairie coreopsis (Coreo*psis palmata*), shooting stars (*Dodecatheon media*), purple coneflower (*Echinacea pallida*), rattlesnake master (*Eryngium yuccifolium*), northern bedstraw (*Galium boreale*), prairie blazing star (*Liatris pycnostachya*), marsh blazing star (*L. spicata*), prairie lousewort (*Pedicularis canadensis*), marsh lousewort (*P. lanceolata*), marsh phlox (*Phlox glaberrima interior*), false dragonhead (*Physostegia virginiana*), blue eyed-grass (*Sisyrinchium albidum*), and Culver's root (*Veronicastrum virginicum*).

During this time, species of the third stage also begin to appear in the developing prairie. These include little bluestem grass (Andro*pogon scoparius*), smooth blue aster (*Aster laevis*), narrow-leaved loosestrife (*Lysimachia quadriflora*), and great plains ladies' tresses (*Spiranthes magnicamporum*).

Succession and Soils

The time needed for the prairie matrix to suppress the weedy vegetation and become dominant is relatively rapid, usually occurring within three to five years. Vagaries of the weather, such as droughts, following the sprouting of seedlings, can extend this time. Even under relatively favorable weather conditions, the dominance of species of the second stage occurs very slowly. This slow pace may, in part, be due to degraded soils.

The soils on which the Fermilab prairie are being restored have been in cultivation for more than 150 years. It is probable that these soils during agricultural use may have undergone certain physical and biological changes, making these soils different from those originally present in presettlement times. Thus, the second and the later stage species do not initially find soil conditions favorable for growth in competition with species of Stage 1.

The presence of physical conditions conducive to vigorous microbiological activity and associated good plant growth in most soils depends upon the binding of soil particles into stable aggregates of various sizes. These provide a range of pore sizes for storage of plant-available water, transmission of water and air, and root growth (Harris et al. 1966, Oades 1984). Cultivation of virgin grassland soils results in a significant loss of water-stable aggregates and often changes the distribution of aggregate size classes (Low 1972, Dormaar 1983, Cook et al. 1988, Jastrow 1987, Miller and Jastrow 1990). It is probable that many prairie species require these water-stable aggregates for their successful entry and establishment in restoration prairies. Prairie gentian (Gentiana puber*ulenta*), which grow from tiny and slow-growing seedlings during their first year, may be an example of a species that requires these water-stable aggregates for their development.

It is also probable that the cultivation and resultant destruction of the prairie flora also caused the extermination of the micro-flora (mycorrhizal fungi, bacteria, and protozoa) characteristic of the virgin prairie soil. Without these symbiotic organisms many prairie plants, such as eastern prairie fringed orchids (Habena*ria leucophaea*) with their mycorrhizal fungi and various prairie legumes (*Amorpha, Baptisia, Lespedeza, Petalostemum*) with their associated bacteria (*Rhizobium spp*), are less competitive within a prairie ecosystem (Dhillion and Friese 1994).

The richer array of Stage1 species and the usual first appearance of Stage 2 species in foci may be due in part to the higher number of water-stable aggregates and richer soil micro-flora than are generally found throughout the matrix.

Support for this hypothesis is shown by the relatively rapid invasion of later successional species into previously cultivated agricultural land from adjacent virgin or near virgin prairie. This has been observed along a railroad prairie at Fermilab.

This same rapid establishment of second stage species into formerly cultivated land has been observed at Gensburg-Markham Prairie, Markham, Illinois. In 1972 this 40.5 ha (100 a) prairie was acquired by Northeastern Illinois University. This prairie consisted of approximately 28.3 ha (70 a) of virgin prairie next to an adjacent 12.1 ha (30 a) naturally restored prairie. This restored prairie had developed on agricultural land removed from cultivation in 1925, and thus there was a period of some 47 years available for its re-establishment. The restored prairie was dominated by three prairie grasses, big bluestem (*Andropogon gerardii*), little bluestem (*A. scoparius*), and Indian grass (*Sorghastrum nutans*) with few second stage plants (Hanson 1975, Post 1980). In the late 1970s efforts were made to further restore this degraded prairie by hand-sowing second- and third-stage species into it. Within a few years populations of these species, including prairie coreopsis (*Coreopsis palmata*), purple and white prairie clovers (*Petalostemum* spp.), and prairie and marsh phloxes (*Phlox* spp.) were able to establish themselves within the degraded prairie.

A similar phenomenon was observed in the restoration of cemetery prairies in Illinois and Indiana (Betz and Lamp 1989). On first observance, a large portion of these cemeteries had been mowed for decades and gave little evidence that they still contained prairie plants. However, around the tombstones and fences there were isolated clumps of big bluestem grass (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), lead plant (*Amorpha canescens*), prairie dock (*Silphium terebinthinaceum*), and compass plant (*S. laciniatum*). Close inspection of the mowed blue grass lawn (*Poa pratense*) with its complement of dandelions (*Taraxacum officinale*) showed widely scattered tiny depauperate prairie plants (dubbed "bonsai plants"), such as purple prairie clover (*Petalostemum purpureum*), prairie gentian (*Gentiana puberulenta*), and heart-leaved golden Alexanders (*Zizia aptera*). When mowing was discontinued, these widely scattered bonsai plants began to recover.

Two years after cessation of mowing, these overgrown bluegrass lawns with the rare nonblooming depauperate plants were burned in the spring. In the following two summers, the cemetery took on the aspect of a matrix prairie with tall bluestem grass (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), wild bergamot (*Monarda fistulosa*), yellow coneflower *Ratibida pinnata*), stiff golden rod (*Solidago rigida*), and compass plant (*Silphium laciniatum*).

Within four or five years after the initial burn, the isolated prairie plants of the second and third stages such as, purple and white prairie clovers, lead plant, prairie gentians, hoary puccoon (*Lithospermum canescens*), and prairie phlox (*Phlox pilosa*) were quickly replacing plants of the prairie matrix. After a decade of recovery, these cemetery prairies resembled virgin prairies with little or no traces of a bluegrass lawn that may have covered them for decades.

In order to speed the entry of the prairie soil micro-flora into degraded prairie soils, it might be necessary to remove a limited number of plugs of soil from the edges of virgin or near-virgin prairies for use in inoculating **foci** within a tract being restored.

It also could be accomplished by first growing plants of the second and third stages in pots with their mycorhizal fungi and then transplanting into the matrix prairie. It might also be done by digging these plants from prairie remnants that are to be destroyed. However, it is difficult to transplant prairie plants into an established prairie since wild animals have a tendency to dig up the plants as soon as they are planted. Very few transplanted prairie plants ever survived their depredations.

Weeds within the Prairie Matrix

When burned annually, the prairie matrix is very competitive against most agricultural weeds, such as ragweeds (*Ambrosia*), mustards (*Brassica*), lamb's quarters (*Chenopodium*), pepper-grasses (*Lepedium*), medicks (*Medicago*), plantains (*Plantago*), smartweeds (*Polygonum*), docks (*Rumex*), foxtail grasses (*Setaria*), clovers (*Trifolium*), and speedwells (*Veronica*). Various thistles, such as nodding thistle (*Carduus nutans*), bull thistle (*Cirsium vulgare*), and even the rhizomatous Canadian thistle (*C. arvense*) will quickly disappear from annually burned tracts.

However, the biennial white sweet clover (*Melilotus alba*) is able to co-exist within the annually burned developing prairie matrix. This Eurasian exotic acts as though it is a true native prairie plant in that it thrives under a prairie fire regime. Regardless of what is reported in the literature, it appears that the time of burning (early autumn, late spring, etc.) has little bearing on its disappearance from the developing prairie. If the prairie is not burned for a few years, this weed maintains a very low profile with only a few plants here and there throughout the tract. However, after the first burn, the plant is back in great abundance. Observations at the Gensburg-Markham Prairie, where the prairie has been burned almost annually for the past 25 years, indicate that over time as the diversity of prairie species increases, white sweet clover decreases in abundance. The periods between flareups of this plant lengthen, and finally the plant disappears within the prairie tract. This phenomenon has also been observed in virgin old settler cemetery prairies (Betz and Lamp 1989). However, all that is needed is for a woodchuck or ground squirrel to disturb the ground and a few white sweet clover plants will find their way back into the area to start the process all over again, at least for a year or two.

Big bluestem grass (*Andropogon gerardii*) and Indian grass (*Sorhastrum nutans*) of the prairie matrix will both slowly eliminate Hungarian brome grass (*Bromus inermis*) and quack grass (*Agropyron repens*) from a developing prairie if the tract is burned annually.

Depending on the water table, reed canary grass (*Phalaris arundinacea*) is slowly outcompeted by both big bluestem grass (*Andropogon gerardii*) on the mesic sites, and prairie cord grass (*Spartina pectinata*) and rhizomatous sedges, such as broad-leaved woolly sedge (*Carex pellita*), on the wetter sites. First indications of its weakening is a reduction in height and the vigor of flowering. Annual burning of the prairie is an absolute necessity in order to achieve a slow elimination of reed canary grass. If the developing prairie is not burned, reed canary grass will outcompete the prairie grasses and take over an area.

WET MEADOWS

Wet meadows are widely scattered throughout Fermilab. Most of these are only a few acres in extent, but there are

some of ten or more acres. They are usually wet in spring with a few inches of standing water. They are dry during summer except for a few days following a heavy rain storm.

While some of these were present prior to presettlement days, others have been recently formed as a result of the construction of Fermilab. Originally, most of Fermilab was agricultural land which was heavily crisscrossed with drain tiles. Thus, when the accelerator ring was built, these tiles were broken and wet meadows began to form in low spots within the ring. A similar situation exists outside of the accelerator ring.

Wet Meadow Succession

In contrast to prairie vegetation which was almost destroyed by agricultural cultivation during the past 150 years or more, some of the wet meadow vegetation has survived in a few small isolated wet pockets that were not cultivated. With the cessation of cultivation in the late 1960s, these degraded marsh remnants began to recover and even spread into new wetlands that were coming into being by the destruction of the drain tiles.

These wet meadows are slowly moving through successional stages. The stages that have been observed include successively: (1) weedy annual stage, with clammy hedge hyssop (*Gratiola neglecta*) and false pimpernel (*Lindernia dubia*); (2) an intermediate stage with sedges (*Cyperus* spp.), spike rushes (*Eleocharis* sp.), rushes (*Juncus* spp.), common water horehound (*Lycopus americanus*), caespitose carices (*Carex cristatella, C. stipata, C. scoparia, and C. vulpinoidea*), monkey flower (*Mimulus ringens*), water heartsease (*Polygonum coccineum*), water knotweed (*P. amphibicum stipulaceum*), and various rushes (*Scirpus acutus*), (*C. atrovirens*) (*S. fluviatilis*) (*S. lineatus*) and) (*S. validus*); and (3) a prairie cord grass stage, showing an increasing prevalence of prairie cord grass (*Spartina pectinata*), blue joint grass (*Calamagrostis canadensis*), and various rhizomatous sedges (*Carex atherodes* and *C. pellita*).

Wet Meadow Enrichment

Over the past two decades efforts have been made to enrich these wet meadows with seed collected on site or obtained by trading seed from local county forest preserve districts. Since planting cannot be done by mechanical sowing or drilling because of the wet ground, seeds are usually hand-sown during the winter months when the ground is frozen over and even covered with snow. This enables the seed to be more evenly distributed throughout the wet meadow. As the snow and ice melt, the seeds fall to the wet soil.

SAVANNA/WOODLANDS

There are approximately a dozen farm woodlots scattered throughout the western part of Fermilab. These are remnants of the once extensive presettlement savanna listed in the first surveyor's notes as the "Big Woods." The dominant tree is bur oak (*Quercus macrocarpa*) along with red oak (*Q. rubra*) and white oak (*Q. alba*). Other trees present in these woods are sugar maple (*Acer saccharum*), shagbark hickory (*Carya ovata*), bitternut hickory (*C. cordiformis*), white ash (*Fraxinus americana*), black ash (*F. nigra*), and basswood (*Tilia americana*).

Like most Midwest woodlots, all have had a history of being grazed by farm animals. Only two of the Fermilab woodlots have retained a good representation of the presettlement ground flora. The remainder have been severely degraded by overgrazing.

Woodland Enrichment

The size of the savanna and woods on site are regularly being enlarged by transplanting young bur oak (*Quercus macrocarpa*) and shagbark hickory (*Carya ovata*) saplings from high density thickets to open fields adjacent to woodlands by use of a mechanical tree spade. Planting is done in such a way as to eliminate the straight fence lines of trees and shrubs that are reminders of a previous agricultural era.

Also, over the past decade efforts have been made to enrich the ground cover of these woodlots either by hand-sowing seed throughout the year or broadcasting seed using a fertilizer buggy. Some of the seed is hand-collected from richer woods on site. Species thus planted include wood mint (*Blephilia hirsuta*), Dutchman's breeches (*Dicentra cucullaria*), sharp-lobed hepatica (*Hepatica acutiloba*), golden seal (*Hydrastis canadensis*), and American gromwell (*Lithospermum latifolium*). Other woodland seed is obtained from neighboring county forest preserve districts by trading prairie matrix seed for woodland seed. This includes wild columbine (*Aquilegia canadensis*), poke milkweed (*Asclepias exaltata*), and ginseng (*Panax quinquefolius*).

Wooded Swamps

There are a few wooded swamps along Indian Creek, a tributary of the Fox River, which drains the southern portion of Fermilab. The dominant tree along this water course is swamp white oak (Quercus *bicolor*). The locally rare kingnut hickory (*Carya laciniosa*) is also found there. Some of the swamp plants found are swamp sedge (*Carex muskingumensis*), hop sedge (*C. lupulina*), common wood reed (*Cinna arundinacea*), sweet-scented bedstraw (*Galium triflorum*), and button bush (*Cephalanthus occidentalis*).

The diversity of species within these swamps is being increased by collecting seed on site for dispersing along Indian Creek.

Effect of Animals on Prairie Restoration

Because of its size (approximately 7000 acres) and diversity of plant communities, many animals species have gravitated to Fermilab. Among the mammals recorded at Fermilab are: white-tailed deer, coyotes, minks, weasels, voles, beavers, red foxes, raccoons, badgers, woodchucks, and opossums. Among the birds there are seven or more pairs of breeding red-tailed hawks, horned owls, short-eared owls in winter, a colony of blue heron, American egrets, upland sandpipers, meadow larks, bobolinks, marsh wrens and rails. During migration a variety of warblers and waterfowl are found in the woods and marshes, including flocks of sandhill cranes. As the prairie develops, there is an ever-increasing diversity of insects, including butterflies, native bees, and flies.

Most of these animal species cause very little damage or problems. However, the white-tail deer are causing serious problems in the restoration of both prairie and woodland at Fermilab. Without any population control this animal has reached epidemic proportions during the last two decades. They feed principally on the flowers of a wide variety of both prairie and woodland species, preventing them from setting seed. Among the woodland species that they are especially fond of are trilliums, Jack-in-the-pulpits, and woodland phlox in the wooded areas. On the prairie tracts being restored they are fond of consuming the flowers of lilies, phloxes, showy-tick trefoils, wild indigos, and shooting stars. Interestingly, they do not seem to like the flowers of the Compositae, such as the goldenrods, asters, coneflowers, and the silphiums. Studies are under way to control their population.

CONCLUSIONS

The changes in the methods of planting and enrichment of the prairie being restored at Fermilab during the past two decades may help others who are interested in large scale prairie restoration.

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