DRAFT

(Document scanned from
hardcopy provided by authors)

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 a) 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 a). During these two decades an effort has been made to add species diversity to the plantings by introducing species of narrower ecological tolerances. Continuous observations of these tracts have provided valuable information on large-scale prairie restoration. This, in turn, has led to: (1) the use of different and more efficient agricultural machines; (2) changes in the methods of collecting, cleaning, and sowing of seed; (3) an increase in the frequency of autumn and spring burns; and (4) the development of new methods for the enrichment of the plantings. Based on the above a method was developed for successional restoration involving the use of seeds of early successional species, i.e., prairie matrix. Within three years this prairie matrix eliminates most of the non-prairie species while providing an adequate fuel load capable of being burned. This initiates changes in the biological and physical structure of the soil necessary for the successful entry of higher successional prairie species into the system. In addition to the prairie restoration project, efforts have been made to increase the species diversity of remnant wetlands and woodlands at Fermilab.

TWO DECADES OF PRAIRIE RESTORATION AT FERMILAB BATAVIA, ILLINOIS

Robert F. Betz
Northeastern Illinois University
5500 N. St. Louis Avenue
Chicago, Illinois 60625, U.S.A.

Robert J. Lootens and Michael K. Becker
Fermi National Accelerator Laboratory
Department of Roads and Grounds
P.O. Box 500
Batavia, Illinois 60510, U.S.A.

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 (41 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 a) of previously plowed and disked black agricultural soil located within the accelerator ring at Fermilab. During the first decade of restoration a total of 156 ha (385 a) were planted, mostly within the accelerator ring. During this time there were a number of changes made in methods of ground cultivation, planting, and species enrichment of the prairie tracts subsequent to the initial planting (Betz, 1986).

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

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 may 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 calamus)* and marsh shield fern *(Dryopteris thelypteris pubescens),* which are not found at Fermilab but may be added.

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

topography. However, the richest in terms of prairie species diversity is Plot 1 with 90 species (Table 1).

During the second decade of prairie restoration, efforts were made to restore the degraded remnant wetland and woodland communities to their more natural states characteristic of the pre-settlement 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.

SUCCESSIONAL RESTORATION

The Concept of Successional Restoration

"Successional Restoration" is the method being used to restore the prairie at Fermilab on the former agricultural fields. This involves an initial planting, using aggressive species that have wide ecological tolerances which will 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 a few 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. Only after the species of the prairie matrix are well established is the species diversity increased by introducing species with narrower ecological tolerances. These species are thus characteristic of the later successional stages.

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 yellow coneflower *(Ratibida pinnate),* 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 that are now included for the list of the second successional stage now numbers 48 (Table 3). Tentatively, list of species designated as third stage include 16 species (Table 4), and 9 species are proposed for a fourth stage (Table 5).

Observations over the past twenty years have shown that it takes approximately two to three 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)* dominates 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 I--Drummond's aster *(A. sagittifolius drummondii);* (c) Stage II--heath aster *(A. ericoides)* and New England aster *(A. novae-angliae);* (d) Stage III--sky blue aster *(A. azureus)* and smooth blue aster *(A. laevis).*

With few exceptions, the sequence of species from the first stage to the fourth stage is similar to the sequence proposed by Peter Schramm, 1990. However, there are differences in what constitutes a stage. Stage I is a combination of Schramm's Stage I (Initial Downgrow Weedy Stage) and Stage II (Intense Competitive, Stand Establishment Stage). Stage II is similar to Schramm's Stage III (Closeout Stage). Stage III and Stage IV 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 mechanically by use of a farm combine tractor. Approximately 8,000 to 10,000 pounds of uncleaned seed are typically collected each year from tracts with the 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)* and showy tick trefoil *(Desmodium canadense),* whose populations quickly decrease under competition within later stage plantings.

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, so as to enhance drying and prevent the buildup of heat. After drying, the seed is stored on the barn floor over winter. It is used for sowing 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 usinq 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.

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 is 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/hectare (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 week 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.

ENRICHMENT OF THE PRAIRIE TRACTS

The matrix constitutes about 24% of the pre-settlement 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, there is also an effort 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 coneflower *(Ratibida pinnate)*, 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 showy 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 preserves in the vicinity of Fermilab. Matrix seed collected at Fermilab is exchanged for seed to be used to enrich 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).*

Since many prairie species produce seed that remain covered within their fruit coat, a 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 which 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 recenty 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.

In that 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 (1) the size of the orifice at the bottom of each compartment and (2) 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 bury the seeds into the soil more efficiently. 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. Cleaned 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 lack some 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 *(*Lob*elia spicata),* prairie lousewort *(Pedicularis canadensis),* marsh phlox *(Phlox glaberrima),* prairie phlox *(P. pilosa),* and blue-eyed grass *(*S*isyrinchium albidum).* Rather than store this seed for months before planting and have it undergo loss of seed viability, it is hand-sown immediately after collection into localized areas with a richer array of species than generally found throughout a planting, designated as foci (sing. focus) or focal spots.

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 prairie plots planted have been burned repeatedly during the past twenty 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 the month of November and early December after most seed has ripened or 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 the onset of burning begins when weather conditions favor fires that move aggressively through 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. In as much as the winter snow flattens and compacts the dried vegetation together, the spring burns are hotter and more vigorous than autumnal burns. They 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 recent planted areas, in which the matrix species are still not well established and dominant, are not grouped into burn units but are burned separately.

The frequency with which the prairies 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 at the same time 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 accumulated considerable amounts of fuel load; (2) tracts which contain substantial amounts of woody vegetation; and (3) tracts which 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 pinnate),* 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 to support a burn.

After five years of annual burns, the prairie matrix usually dominates a large portion of the tract. The dominant grasses are big bluestem *(Andropogon gerardii)* and Indian grasses *(Sorghastrum nutans).* In low spots, prairie cord grass *(Spartina pectinata)* is slowly 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),* 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 gerardii),* 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)* and 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 six feet 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),* showy black-eyed Susan *(Rudbeckia subtomentosa),* and various species of goldenrod: grass-leaved goldenrod *(Solidago gymnopsermoides),* 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, specimens of species belonging to the second stage are 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),* purple prairie clover *(P. purpureum),* marsh phlox *(Phlox glaberrima interior),* false dragonhead *(Physostegia virginiana),* and Culver's root *(Veronicastrum virginicum).*

From the tenth to the fifteenth year, the second-stage 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 maculate)*, Illinois tick trefoil *(Desmodium illinoense)*, bottle gentian *(Gentiana andrewsii)*, yellow gentian *(G. flavida)*, cardinal

flower *(Lobelia cardinalis)*, cowbane *(Oxypolis rigidior)*, prairie paraley *(Polytaenla nuttallii)*, and glaucous white lettuce *(Prenanthes racemosa).*

Between the fifteenth and twentieth year, second-stage species increase in numbers and begin to expand the foci. New populations of these and other second wave species slowly begin to appear throughout the tract. The additional species of the second stage are prairie coreopsis *(Coreopsis 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 *(Andropogon 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. Further, 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 is 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 and making these soils different from those originally present in pre-settlement times. Thus, the second and the later-stage species do not initially find soil conditions favorable for growth in competition with species of the earlier Stage I.

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, Chesters, and Allen, 1966; Oades, 1984). Cultivation of virgin or long-term grassland soils results in a significant loss of water-stable aggregates and often changes the distribution of aggregate size classes (Weaver and Zink, 1946; Low, 1972; Tisdall and Oades, 1982; Dormaar, 1983; Cook, B. D, J. D. Jastrow and R. M. Miller, 1983; Jastrow, J. D., 1987, Miller, R. M. and J. D. Jastrow, 1990). It is probable that many prairie species require these water-stable macro-aggregates for their successful entry and establishment in restoration prairies. Prairie gentian *(Gentiana*

puberulenta), which has tiny and slow-growing seedlings during the 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 orchid *(Habenaria leucophaea),* with their mycorrhizal fungi and various prairie legumes *(Amorpha, Baptisia, Lespedeza, Petalostemum)* with their associated bacteria *(Rhizoblum ssp.),* are less competitive within a prairie ecosystem.

This hypothesis is supported 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.

The 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 47 years for its reestablishment. This restored prairie was dominated by three prairie grasses, big bluestem *(Andropogon herardia),* little bluestem *(A. scoparius),* and Indian grass *(Sorghastrum nutans)* with few second-stage plants (Hanson, 1975, Post 1980). In the late 1970's 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 with the degraded prairie.

In order to speed the entry of the prairie soil micro-flora into degraded prairie soils, it might be necessary to soil from the edges of virgin or near virgin prairies to inoculate foci within a tract being restored.

Weeds within the Prairie Matrix

When burned annually the prairie matrix is very competitive against most agricultural weeds, such as ragweed *(Ambrosia, spp.),* mustard *(Brassica, spp.),* lamb's quarter *(Chenopodium, spp.),* pepper-grass *(Lepedium, spp.),* medick *(Medicago, spp.),* plantain *(Plantago, spp.),* smartweed *(Polygonum, spp.),* dock *(Rumex, spp.),* foxtai1 grass *(Setaria, spp.),* clover *(Trifolium, spp.),* and speedwell *(Veronica, spp.).* Various thistles, such as nodding thistle *(Carduus nutans),* bull thistle *(Cirsium vulgare),* and even the rhizomatous Canadian thistle *(Cirsium 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, R. F. and H. F. 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 *(Sorghastrum 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)* on the wetter sites. First indications of its weakening are 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 the 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 rainstorm.

Some wetlands were present since pre-settlement days, and others have been recently reformed as a result of building 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 1960's, these degraded marsh remnants began to recover and even spread into new wetlands, which were coming into being by the destruction of the drain tiles.

These wet meadows are slowly moving through three stages. The first is the weedy annual stage with clammy hedge hyssop *(Gratiola neglecta)* and false pimpernel *(Lindernia dubia).* The second is 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 ringers),* water heartsease *(Polygonum coccineum),* water knotweed *(P. amphibicum stipulaceum),* and various rushes *(Scirpus acutus, C. atrovirens, S. fluviatilis, S. lineatus* and *S. vallidus).* The third stage shows 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-sowed 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 twelve farm wood lots scattered throughout the western part of Fermilab. These are remnants of the once extensive pre-settlement 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),* shaghark hickory *(Carya ovate),* 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 pre-settlement ground flora. The remainder has 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 ovate)* 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 hirsute),* Dutchman's breeches *(Dicentra cacullaria),* sharplobed hepatica *(Hepatica acutiloba)* golden seal *(Hydrastis canadensis),* and Americn 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. This tributary of the Fox River drains into the southern section of Fermilab. The dominant tree along Indian Creek is the swamp white oak *(Quercus tricolor).* 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 *(Calium triflorum),* and button bush *(Cephalanthus occidentalis).* Collecting the seed from Fermilab and dispersing it along Indian Creek is increasing the diversity of swamp species.

Acknowledgments

We would like to thank Dr. Herbert F. Lamp, Professor Emeritus, Northeastern Illinois University for his constructive comments on this manuscript.

Literature Cited

Betz, R. F. (1986). One Decade of Research in Prairie Restoration at the Fermi National Accelerator Laboratory (Fermilab) Batavia, Illinois. Proceedings of the Ninth North American Prairie Conference. Tri-College University Center for Environmental Studies, Fargo, North Dakota-Moorhead, Minnesota, pp. 179-185.

Betz, R. F. and H. F. Lamp (1989). Species composition of old settler-silt loam cemetery prairies. Proceedinqs of the Eleventh North American Prairie Conference, Lincoln, Nebraska, pp. 33-39.

Cook, B. D., J. D. Jastrow, and R. M. Miller (1988). Root and mycorrhizal endophyte development in a chronosequence of restored tallgrass prairie. New Phytology 110: pp. 355-362.

Dormaar, J. F. (1983). Chemical properties of soil and water-stable aggregates after sixty-seven years of cropping to spring wheat. Plant Soil 75: 51-61.

Harris, R. F., G. Chesters, and O. N. Allen (1966). Dynamics of Soil Aggregation. Advances in Agronomy 18: pp. 107-169.

Jastrow, J. D. (1987). Changes in soil aggregation associated with tallgrass prairie restoration. American Journal of Botany 74 (11): pp. 1656-1664.

Low, A. J. (1972). The effect of cultivation on the structure and other physical characteristics of grassland and arable soils (1945-1970). Journal of Soil Science 23: pp. 363-380.

Miller, R. M. and J. D. Jastrow (1990). Hierarchy of root and mycorrhizal fungal interactions with soil aggregation. Soil Biological Biochemistry 22 (5): pp. 579-584

Oades, J. M. (1984). Soil organic matter and structural stability: mechanisms and implications for management. Plant Soil 76: pp. 319-337.

Schramm, P. (1990). Prairie Restoration: A Twenty-five Year Perspective on Establishment and Management. Proceedings of the Twelfth North American Prairie Conference. University of Northern Iowa, Cedar Falls, pp. 169-177.

Tisdall, J. M. and J. M. Oades (1980). The effect of crop rotation on aggregation in a red-brown earth. Australian Journal of Soil Research 18: 423-433.

Weaver, J. E. and E. Zink (1946). Annual increase of underground materials in three range grasses. Ecology 27: 115-127.

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**	

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 pinnate (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 tenulfolia (slender false foxglove)
Andropogon scoparius (little bluestem)
Anemone canadensis (Canadian anemone)
Anemone cylindrica (thimbleweed)
Asclepias tuberosa (butterflyweed)
Asclepias sullivantti (prairie milkweed)
Aster novae-angliae (New England aster)
Aster ericoides (heath aster)
Cacalia plantaginea (Indian plantain)
Carex bicknellii (prairie sedge)
Cicuta maculate (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 andrewsli (bottle gentian)
Gentiana flavida (yellow gentian)
Gentiana quinquefolia (still gentian)
Helianthus rigidus (prairie sunflower)
Krigia biflora (false dandelion)
Lathyrus palustris (marsh vetchling)
Liatris pycoostachya (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)

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)
Haptisia leucophaea (cream wild indigo)
Bromus kalmli (Kalm's brome grass)
Chelone glabra (turtlehead)
Heuchera richardsonii grayana (alum root)
Lithospermum canescens (hoary puccoon)
Lysimachia quadriflora (narrow-leaved loosestrife)
Panicum leibergli (prairie panic grass)
Polygala senega (Seneca snakeroot)
Spiranthes magnicamporum (ladies' tresses orchid)
Sporobolus heterolepis (prairie dropseed)
Valeriana ciliate (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 hirsute (yellow star grass)
Lilium philadelphicum andinum (prairie lily)
Oxalis violacea (purple wood sorrel)
Scutellaria parvula leonardii (small skullcap)
Viola pedatifida (prairie violet)