Proceedings of a Symposium on Prairie and Prairie Restoration : first held on September 14 and 15, 1968 at Knox College, Galesburg, Illinois. 1970

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Proceedings of a Symposium on

Prairie and Prairie Restoration

FIRST HELD ON SEPTEMBER 14 & 15, 1968
AT
KNOX COLLEGE, GALESBURG, ILLINOIS

Edited by
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Preface

On September 14 and 15, 1968, a symposium on prairie and prairie restoration was held at Knox College, Galesburg, Illinois. With the almost complete disappearance of tall-grass prairie in the Midwest, and the continuing threats to the few remaining prairie remnants, there has been a renewed interest in the subject of prairie by people from many different areas of environmental concern. This was especially evident by the attendance of 120 enthusiastic prairie devotees focusing their concentrated attention on the topics of prairie research, conservation and restoration.

A number of excellent papers were presented most of which have been included in these proceedings. Debate was lively at times on such classically debatable topics as causes of grassland vs. forest. The session on prairie restoration was of special interest because of the number of restoration projects that have very recently been started. The two-day meeting concluded with a field trip to the Knox College Biological Field Station to view a variety of natural habitats including several restored prairie plantings of various ages. One special highlight of the program was a presentation by Jim Wilson of outstanding colored slides of grassland accompanied by a very meaningful narrative.

The group attending was diverse with the academic areas of Botany, Plant Ecology, Zoology, and Soil Science well represented, along with park naturalists, conservationists, landscape architects, historians, and interested laymen also attending and participating. In spite of diverse backgrounds, all persons attending shared an enthusiastic and very special interest in prairie and this resulted in what was described by some as a very special "happening."

Thanks are due to all those who attended, for they made the "happening" possible. Special thanks are due to the authors for contributing the papers that comprise these proceedings.

PETER SCHRAMM

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PETER SCHRAMM.

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Keynote Address: MAN - ENVIRONMENT COLLISION

DAVID ARCHBALD

Managing Director of the Arboretum and Wildlife Refuge, University of Wisconsin, Madison

I. MAN-ENVIRONMENT COLLISION?

Are man and his environment on a collision course? Both environmental scientists and statisticians tell us "Yes!" But where, when, and how great the collisions are questions that depend on man's course of action. The collisions will indeed be painful—mass famine in an environment degraded to a point where the survival of man will be in doubt. If drastic controls are introduced immediately to check the population-pollution spiral, the impact of the collisions will be minimized.

Recent answers received to environmental questions raised over the past decade or two have been discouraging. True, our citizenry is far more concerned today than a few years ago over man's degraded natural environment. But the big concern is whether the citizenry is aroused enough to take effective action immediately? It is said, "Where there's a will there's a way." We have already closed many "ways" and are closing more each day. Many animal species have and are becoming extinct, plant communities eradicated, non-renewable resources depleted, bodies of water irreversibly polluted—all compounded by a runaway population. We now need an extra measure of "will." Environmental scientists agree meaningful options will remain for preserving a quality environment only if a concerned and enlightened citizenry aggressively pursues and demands this environment.

II. HISTORICAL

Actually a series of local or regional collisions have already occurred dating back to the time when man moved out of the Mesolithic into the Neolithic, or Stone Age, about 10,000 B.C. At this point he walked out of the "woods" and left behind over a million years of natural evolution, of natural interaction with all the other plants and animals on earth. Man had "arrived." He had become a farmer. He turned from simple wild food gathering to agriculture — domesticating animals and raising crops. Rats, which he formerly ate, became competitors for his grain. His gardens promoted unnatural concentrations of single-plant species and permitted certain insect species to build high populations, too. These insects no longer had to expend much time and energy on foraging for food over a diversified plant community. Native plants, in attempting to naturally revegetate his croplands, also competed. Formerly ignored, now they were weeds.

These competing animals and plants had not really changed, but nevertheless they were now pests. It was true then, as it too often is today, that we see things not as they are but as we are.

Thus, agriculture was man's first attempt to modify his local ecosystem. He replaced a naturally evolved system with an unnatural system and in so doing set himself apart from his natural environment. Consequently, he experienced his first minor collisions with his environment.

By about 6,000 B.C., man had learned to irrigate his crops and the world's first civilization developed—the Sumerians of Mesopotamia. Further population increase created cities like Nineveh and Babylon. Lumber came into demand and the forests on the upland slopes of the Tigris and Euphrates were cut to fill the need. Soon thereafter, the denuded mountains relinquished their soil to rains which eroded the denuded uplands, washing a sea of mud into the irrigation ditches. The Sumerians removed silt until it was piled up 50 feet high along the banks. With the primitive tools of that age further dredging became impossible. The irrigation systems began to break down. This, with man's new-found enemies—plant and animal pests, caused crop failure. Fish died in the muddy river waters. Starvation ensued. Sumeria began its decline. Once again, man had modified his ecosystem, won temporary benefits and destroyed his environment in the process.

This drama, with the same leading character, can be recounted over and over. Only time and place change: the locust swarms of ancient Egypt were mentioned in Exodus in the Bible; epidemics such as bubonic plague which killed a fourth of Europe's population in the 1300's; the drought-caused famine of 1877–79 in China where 9 million died; and the global flu killed 25 million in 1918–20.

III. POPULATION: BIRTHQUAKE

Thomas Malthus correctly predicted in 1798 our current population dilemma.

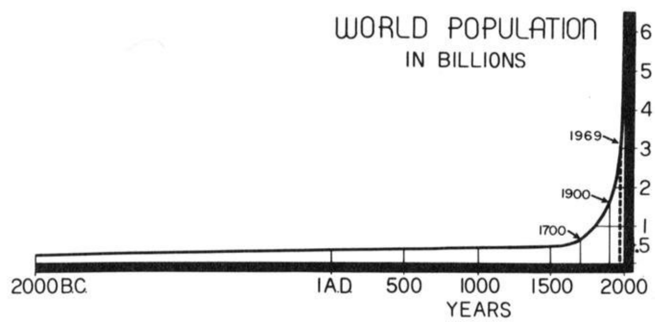

FIGURE 1

South America's population is presently doubling every 22 years, as suggested in Table 1.

TABLE 1

World population (1) in millions of people, by "developed" and "underdeveloped" continents.

Year·	1965	2000	% increase
So. America	240	624	160%
Africa	306	768	118%
Asia	1,800	3,300	83%
Total "underdeveloped"	2,346	4,692	100%
No. America	213	354	61%
U.S.S.R.	231	353	53%
Europe	440	527	20%
Total "developed"	883	1,234	40%

Increase in any population occurs when the birth rate exceeds the death rate. Man, through his technological discoveries over the past few centuries, has sharply reduced death rates. Through this same technology, he also has been able to increase the production and distribution of food—but not fast enough.

IV. POPULATION: IMPACT ON ENVIRONMENT

A. The Prodigal Population

Man, in his eagerness to rush toward an unknown destination, has been *prodigal* indeed! When the Pilgrims stepped ashore on Plymouth Rock, North America was an unending wilderness, seemingly inexhaustible yet hostile—a challenge to the settlers' very survival. Consequently, a cultural pattern of natural resource exploitation and building developed which has continued down to the present day. In Table 2 we can see a few of man's "triumphs" in his "battle with nature."

TABLE 2

SOME NATURAL RESOURCES: THEN AND NOW

Natural Resource	Original Acreage	Now	% of original resource remaining
Wis. prairies	2,000,000	Less than 20,000	less than 1%
Calif. redwoods	2,000,000+	(Redwood park 58,000)	3%
Passenger Pigeon	5,000,000,000	0	0
Bison	50,000,000	6,000	1/100 of 1%

It is a tragic irony that the U. S., the world's most affluent country, has been able to afford to preserve so little of its wilderness. The tiny percentage of the natural resources we have today was preserved by default, not by foresight. Either the particular resource became too scattered or too inaccessible to exploit profitably. Virgin eastern white pine forests or bits of prairie are such isolated resources. Many of our natural areas are hardly virgin, having been subjected to some grazing, selective lumbering, fire, erosion, chemical invasion and other forms of abuse. We are presently converting every year over one million acres of farm and wildlands to highways and building sites.

True, natural resources made possible the phenomenal development of the U. S. But why did so many resources have to be 98–100% depleted?

This same story holds for each continent, only the chronology is different.

B. Population-Pollution Syndrome

In recent decades, man's chemical assault on his environment has surpassed even his physical attack (briefly discussed above). The "effluence of his affluence"—municipal and industrial wastes, vehicular exhaust, atmospheric dust, chemical pesticides used on crops, lawns and gardens—is staggering.

AIR

Air pollution now costs every American $65 per year in property damage. Moreover, air pollution takes thousands of lives prematurely by aggravating bronchial ailments. Yet, the total 1969 Congressional outlay for air pollution control is about 45 cents per person.

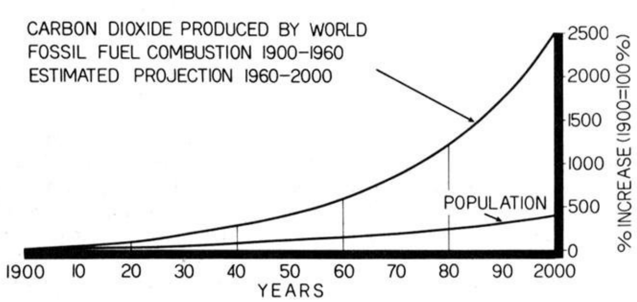

FIGURE 2

Figure 2 shows the relative increase in world population and combustion of fossil fuels (coal, liquid hydrocarbons, natural gas and lignite) (2). The carbon dioxide curve is presented as an indication of man's ability to release long-stored energy into his environment, energy that throws the environment into ecological disarray. With more and more energy available, man is able to plow, cut, net, mine, or bulldoze for the quick dollar. We are accumulating waste by-products roughly at the rate the CO_2 curve is ascending. So, environmental degradation is progressing considerably faster (see also Figure 3) than the population increase depicted in Figure 1.

The climatologists are not in complete accord in their interpretation of the significance of atmospheric CO_2 accumulation. It has been suggested that atmospheric warming due to an increased CO_2 "greenhouse effect" could melt the Antarctic ice cap and raise sea level 400 feet. If this takes 1,000 years, and it could occur sooner, the seas would still rise 4 feet every decade and in 30 years many of the world's great seaports would be largely inundated. Indeed, between 1885 and 1940 the average surface temperature over the entire earth showed a rise of .9° F. But between 1940 and 1960 the temperature dropped .2° F. Some scientists attribute this decrease to the abrupt increase in the atmospheric dust (3). Unfortunately, it is nowhere near as simple as one injection negating the effects of a second. Atmospheric dust and CO_2 have quite different effects on such important factors as light quality and intensity, photosynthesis, plant and animal respiration, wind velocity and direction and water acidity.

One estimate of the various pollutants being released into the air is presented in Table 3 (4).

TABLE 3

ESTIMATED U. S. AIR POLLUTION TONNAGE PER YEAR

Source	Millions of Tons	% of Total
Cars, trucks and buses	85	65
Manufacturing industry	22	17
Electric power plants	15	12
Heating of homes and buildings	8	6
Total	130	100

WATER

Certain lower forms of life survive without oxygen. All forms of life, at least on this planet, require water to survive and reproduce. Man can go many weeks without food but only a few days without water. Clean air and clean water are man's two most important natural resources. Yet look at what we have done to Lake Erie, one of the world's great freshwater lakes.

Through mismanagement and abuse, we have converted a clean, blue lake into an aquatic desert, listless and murky green.

In 1900, the whole U. S. sewage system discharged less than 10 million pounds of phosphates annually. By 1964, the discharge totaled 250 million pounds, with synthetic detergents being a major contributor. The National Research Council warned two years later that by the mid-1980's the nation's municipal wastes are expected to have a biological demand equal to the oxygen available in the entire summertime flow of the nation's river systems. In other words, if the nation's mid-1980 municipal water were uniformly dumped into the country's streams and rivers, the water's dissolved oxygen would be completely depleted and all aquatic life exterminated.

Finally, the so-called clean power from nuclear energy has two harmful waste products: lethal and crippling radioactive wastes and the discharge of heated water used in the cooling process. Thermal pollution reduces dissolved oxygen levels and encourages algae growth—illustrating again that we cannot get something for nothing.

Changes similar to those in Erie are occurring in Lake Michigan. Ominous is the accumulation of insecticides. Just as we failed to grasp what was happening in Lake Erie until too late, we never realized DDT and related insecticides move as readily as they do through the biosphere. Nor did we realize until recently that DDT, being nearly insoluble in fat, is concentrated in the fatty tissues of predatory animals on up the food chain. Coho salmon are at the top of the food chain in Lake Michigan. Their eggs have such high concentrations of DDT that salmon reproduction has been severely disrupted. Table 4 illustrates this biological concentration.

TABLE 4

DDD (a breakdown product of DDT) entered Clear Lake, Calif., at .02 ppm. Concentrations were as indicated 13 months later (5).

Organism	Parts per million (ppm)	Increase over initial concentration
Plankton	10	500x
Fish that live on plankton	903	45,000x
Fish that eat fish that eat the plankton	2,690	134,500x
Birds that eat fish that eat the plankton	2,134	106,700x
Man, who stands at the food chain's top	??	??

A similar study was conducted at the Hanford, Washington, atomic power plant on the Columbia River. Small amounts of various isotopes were released into the water and followed in natural food chains. Hanford scientists found that radioactive phosphorus appeared in eggs of ducks and geese in concentrations 200,000 times higher than the solution released into the water, and occasionally 1.5 million times higher. Although the eggs hatched, the genetic damage to the species hasn't yet been determined.

DDT and/or its derivatives have been found in surprisingly high concentrations in Antarctic penguins (19–83 ppm), Bermuda petrels (58 ppm), Arctic peregrine falcons in northern Alaska (414 ppm) and California bald eagle fat (2,800 ppm), in every fish so far sampled by the Wisconsin Department of Natural Resources and the University of Wisconsin, and is widespread in oceanic fishes (6). Even atmospheric dust sampled over the Caribbean isle of Barbados has its share of DDT —14 ppb (3).

What about the half-million chemicals the FDA estimates we are now exposing ourselves and our environment to? FDA estimates the number is increasing by 400 to 500 per year (see Figure 3). We are begging the question of how these chemicals directly affect us and all other organisms. But what are the possible effects of various chemicals in combination? We just do not know.

Aldo Leopold (7) wrote 20 years ago: "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." Many of the chemicals we are using are destroying or dislocating biotic communities.

Figure 3 indicates the extent to which Americans will pollute their environment in the next 30 years (8) unless broad protective measures are adopted.

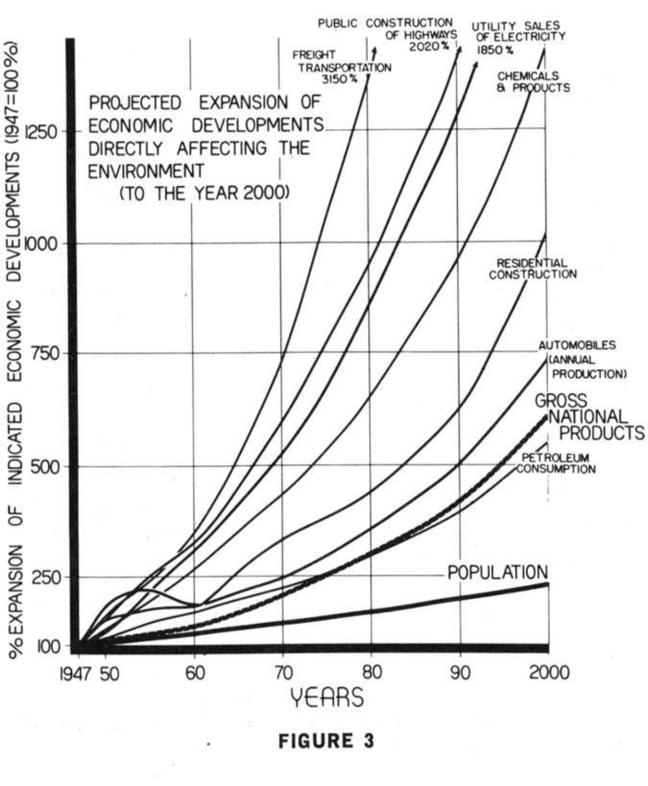

FIGURE 3

What comfort can we derive from the fact that our Gross National Product is expected to double in the next 20 years? After comparing the socio-ecologic environment in the U. S. and the world in 1949 and 1969, I see little cause for optimism for 1989 unless our national and world values change. When a GNP is sufficient to meet its people's basic biological and social needs, the value of a growing GNP depends on the values, wisdom and goals of the nation producing it. We are still selling our virtue to buy wealth. For our own long-term survival, we must chart and follow a course designed ". . . to preserve the integrity, stability and beauty of the biotic community."

V. WHAT SIGNIFICANCE: ECOSYSTEMS?

Man is clever in adapting but also brazen and arrogant. He has insinuated himself into the forefront of the biotic community. And in his scramble to dominate, he has broken nearly every ecological principle of energy flow, isolation, community interaction and population control. He is trying to rule without knowing nature's rules. The more he manages, the more managing he has to do. If he extirpates a natural predator, then he has to assume that predator's role or risk being overrun by the now uncontrolled prey. Can he poison the pest plants and animals without poisoning the pollinating insects, honeybees, earthworms, or the ocean diatoms which produce 70 percent of the oxygen we breathe?

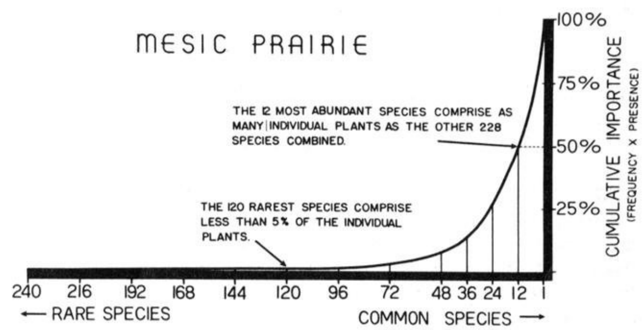

FIGURE 4

Let us consider Figure 4, which shows the relative contribution of the rare and common prairie plant species to the total percentage importance of all the species. This represents, in simplified form, one aspect of one strand in a complex web of the mesic prairie, one segment of the biotic continuum in southern Wisconsin (9). Almost identical curves exist for other types of prairies. And similar curves would reflect the same relative composition of the prairie birds, mammals, insects, fungi, bacteria, or any other group of organisms.

One of the most obvious and significant points demonstrated in Figure 4 is that the presence of the great majority of the species goes unnoticed. In other words, without detailed field research and inventory, far more than half the species could be eliminated without man's knowing it. Man drains this vital genetic pool unwittingly. Usually he becomes aware of ecosystem dislocation only when his own ox is gored, when "his" multi-million pound yield of Lake Erie ciscoe, the dominant species, dwindles to nothing. The point is that ecologists now recognize many intimate inter- and intra-specific relationships, but what they don't know far outweighs what they do.

The extent to which all species are "hooked in" to each other is remarkable. This interlocking of species moved Leopold to comment: "How do we know but when we pick a pasque flower but what we change the course of a star."

That we have been unrestrained in picking pasque flowers is evident from—

MAN'S HAND ON THE LANDSCAPE

Before	*After*
Natural ecosystem	Man-dominated ecosystem
Chipmunk and mink	House mice and rats
Butterflies and luna moths	Houseflies and house moths
Orchids and trilliums	Ragweed and thistles
Gamebirds and songbirds	Housesparrows, starlings and pigeons
Game fish	Bullheads and carp
Earthworms and fireflies	Termites and cockroaches
Prairie community	Corn monoculture
Blue skies	Brown haze
Blue water	Green? Black? Brown water?
Tens of thousands of species interacting in a stable, dynamic, self-perpetuating community	A handful of man-competing species almost wholly dependent on an unstable man-controlled, man-driven community.
"UNDEVELOPED?"	"DEVELOPED"
Quality environment!	Ugh!

VI. OUR PROBLEM(S)

The problem is multi-faceted. It involves an exploding population, ignorance of ecological principles and exploitation of the world's limited resources. We have unleashed super-powerful forces which we may not be able to check: a run-away population, poverty and pollution—chemical, physical, thermal and biological (see Figures 1, 2 and 3).

As these forces continue to gain momentum, our ability to control our destiny diminishes proportionately. Given our present anti-pollution programs and laws, we cannot possibly even hold the line at the present level of pollution, let alone reverse it. If, in the next 15 years, we can muster the knowhow and money to rid the U. S. of the equivalent of the total 1969 effluent, we will still be polluting the environment at today's rate. Our effluent will have doubled by then because of increased population and increased per capita consumption of apparently indispensable creature comforts.

Why do we find ourselves in this bind? Primarily because of our money-making drives—dollars and drachmas, rupees and rubles, pounds and pesos—money takes precedence over all other values. Minimize costs and maximize benefits. This is fine if we consider the input of all the costs, monetary and environmental, and output of all the benefits, short and long-term.

In this milieu, the conservationist is often hampered by cumbersome legal machinery. Civil and criminal laws have been evolving over the centuries, whereas the body of anti-pollution law is relatively new and very incomplete. A party or chemical suspected of polluting is innocent until proven guilty. In some cases of pollution, years may slip by before enough scientific proof of damage can be gathered. By this time, irreparable damage may have occurred.

Government is a balance of conflicting interests. Until a need is clearly demonstrated, in some cases "over-demonstrated," little is done. Hence, the term "government by crisis." This is especially true of the natural environment where man is so woefully ignorant of its extreme intricacies and delicate balances. Because of our lack of understanding, by the time scientists suspect environmental deterioration it is usually far advanced. Moreover, because it usually costs the pollutor more money initially to quit polluting or to adopt precautionary measures, he is unlikely to act on his own.

A case in point is the 800-square-mile oil slick fed by a ruptured Union Oil well off Santa Barbara, California. Warnings about the chance of such a leak were ignored 10 years ago. Santa Barbara officials, fearing pollution from the off-shore oil rigs, persuaded the Interior Department in 1967 to create a two-mile buffer zone beyond the state demarcation line inside of which no drilling could take place. When oil slicks began to appear along the shoreline last year, Santa Barbara asked Interior officials to extend the buffer zone. (It would have encompassed the Union Oil rig and avoided the disaster.) The Interior Department, however, reassured the city that the drilling was under close surveillance, well aware that rentals, royalties and bonus payments from the Santa Barbara concession meant $1.6 billion for Government coffers. Meanwhile, Sen. Edmund Muskie of Maine and Sen. Jennings Randolph of West Virginia voiced fears of pollution from offshore drilling. But the federal government didn't act until too late, until the slick appeared.

The Santa Barbara mess illustrates government-by-crisis, yet isn't as critical as the slow degradation of Lake Erie.

TWO CASES OF ENVIRONMENTAL POLLUTION

Atypical	*Typical*
Santa Barbara oil slick	Lake Erie
Sudden	Relatively slow
Visually dramatic	Visually undramatic; one year was much like the previous
Instant property damage	Property damage, but not as obvious
Responsibility easily fixed	Responsibility difficult to fix—thousands of polluters
Biological recovery: 5? 25? years	Biological recovery: centuries, if ever

Lake Erie points up several aspects of man's role as despoiler of the environment, aspects of which society is usually unaware. The despoiling process is usually gradual, in man's own time scale. Total property and esthetic damage may be staggering but rarely fully appreciated because the loss is not abrupt. There is difficulty in assigning blame. Too often the stupid response we get is "that's the cost of progress." Little or no heed was given to the cost of environmental degradation when the cost/benefit ratio was considered for the various economic ventures in the Erie basin.

The adage "an ounce of prevention is worth a pound of cure" takes on special significance in resource management because so often there is no cure for environmental pollution. We hear about "cleaning up" Lake Erie, chemically perhaps. But we will be about as successful in the lake's biological restoration as all the king's horses and all the king's men were in putting Humpty Dumpty together again. We are convinced technology is waiting in the wings to rescue mankind from himself. Nonsense. That's wishful thinking and specious reasoning. Our unbridled faith in our own technological ability—reinforced by the Apollo space shots, heart transplants, etc.—is simply a relative thing. Comparing such accomplishments with the complex chemical, physical and biological interrelationships of Lake Erie is like comparing the complexity of a single leaf with that of a whole forest. Killing an organism is infinitely easier than bringing it back to life. And it appears this will remain so for the foreseeable future.

Another instance of our over-confidence in our technology concerns the world's food crisis. We hear how we will farm the unlimited resources of the sea. First, the sea's resources are as limited as our knowledge about how to farm it. Let us look at the record. In 1955, the world catch of marine food would have provided enough calories to support 23 million. A decade later, enough calories for 46 million. But, during this same decade when the seas yielded food for just 23 million more, the world population increased by 500 million. Hardly encouraging. Moreover, to cause considerable damage to the seas, all we need to do is pollute coastal waters. This would prevent the reproduction of many species harvested at sea.

Famine is here: 15,000 are dying from starvation daily and millions are suffering from malnutrition. And apparently, regardless of our technology and ambitious programs, the crisis is worsening. Projected dates of widespread famines vary from 1975 (10), 1975-80 (11), according to the U.S.D.A., as late as 1984.

We Americans must check our own population growth. "Saying that the population explosion is a problem of underdeveloped countries is like telling a fellow passenger, your end of the boat is sinking," asserts Paul Ehrlich (12).

Another critical part of our problem is that we are daily inundated with a torrent of "facts," often apparently conflicting, about racism, Vietnam, the generation gap and even population-pollution problems. We must, however, keep these issues in perspective. Is it not to be expected that with more people going in more directions there will be more social conflict? The real danger lies in wasting our energies in fruitless nation-to-nation and man-to-man conflict, which only keeps us from facing the universal challenge—mass famine in a degraded environment.

That Americans are not alone in their pollution problem is evident from the following two excerpts from Soviet publications.

Pravda recently asserted (13) "Every violation of hygienic rules and sanitary norms, large or small, has a direct effect on the people—their mood, their attitudes, their health. We have received many letters protesting water and air pollution. The working people propose the adoption of a number of legal measures to put an end to instances of this barbarous attitude toward nature."

"The problem of geohygiene (earth hygiene) is highly complex and closely tied to economic and social problems. This problem can therefore not be solved on a national and especially not on a local basis. The salvation of our environment requires that we overcome our divisions and the pressure of temporary, local interests," says Andrei Sakharov, the Russian Nobel prize winner in physics (10).

Harrison E. Salisbury comments on Sakharov's new book, "There is roughly a quarter century left before the year 2000. Sakharov does not claim universality for his thoughts. But he would agree that unless his blueprine—or some reasonable variation—is adopted by the principal societies of the world, the prospects of survival into the second millennium are virtually nil."

VII. COURSES OF REACTION

It is already too late to avoid the largest-scale man-environment collisions ever. All we can do now is to react to the crisis so as to minimize the impacts.

First, the population-pollution problem is of such staggering magnitude that our response must be of even *greater* magnitude.

Second, programs of meaningful proportions can and will be mounted only through or with governments—especially the Federal Government, but also state and local governments. Because governments react to today's and not tomorrow's crisis, the population-pollution problem must be brought into sharp focus—in the here and now, not elsewhere years from now. Otherwise, the government will wait years to assure itself the problem really affects us. And then it will be too late. The government is only slightly convinced, as evidenced by its limited efforts. But because of the critical nature of this global problem, we cannot afford partial conviction. We must be completely convinced and completely committed!

Here's what each of us can do:

1. Get involved. Learn the national and local issues of birth control and pollution. Each of us contributes one unit to the population and one unit to the pollution mess. It is our responsibility, therefore, to become informed on the problems. It will take an immense number of us to make the government aware of the problems' scope and hence the scope of government reaction required.

2. The mass media. Some persons in the mass media such as Arthur Godfrey are well informed on our environmental problems. In a recent address (14) to the Advertising Council, Godfrey remarked: "Nowadays, I question *any* value that does not take into account the total ecology of our planet. Any personal deed, any business transaction . . . that does not carry with it all precautions against injuring the environment . . . must be promptly and vigorously challenged." Admittedly few mass media individuals have this ecological awareness. Those that are unaware, *must* become informed so that they can, in turn, help inform the public.

3. Support legislation which helps control population increase and pollution.

4. Initiate legislation. If you observe some act of pollution, notify the proper law-enforcement agency. If this type of pollution isn't outlawed, get your elected representative to introduce the appropriate legislation.

One bill worth supporting would be legislation to revoke existing tax exemptions for dependent children. Because more children require more goods and community services, why shouldn't the parents ultimately responsible for creating the demand be held responsible for meeting it? If this were so, they would be more careful on the production line. At the very least, introduction of such legislation would focus attention on the population problem.

5. Consumer beware. Don't judge an apple by its unblemished skin—it may be the poisoned one. It may contain pesticide residues. Although the FDA has set maximum tolerance levels for pesticides in food, it is impossible to check millions of tons of farm produce. The farmer knows this, too. We Americans must accept a little less gloss to our apples.

6. Write letters. Your political representatives must realize their constituency is alarmed. Urge your friends to write letters.

7. Group action. Many local groups already have become aroused and gained momentum—the Audubon Society, Sierra Club, Izaak Walton League, League of Women Voters, natural beauty councils, garden clubs, etc. Your local county agent can list more. Service organizations such as Chambers of Commerce, Rotarians, Lions, Elks, etc. are always willing to support worthwhile projects. If none of these seems to fill your needs, discuss population-pollution with your friends and form your own group.

8. Teach ecology. Is it being taught in your local schools? If not, why not? Environmental ethics must be inculcated in the young.

9. Some conservatism please. As any resource manager will explain, our resources are limited. When it comes to a debate over exploitation or preservation of a resource, take the conservative stance—urge preservation until we can decide wisely on its highest and best long-term use. This is axiomatic. Because our knowledge pool is doubling every 10 years, we will know eight times as much by the year 2000. Therefore, we will be able to make better decisions on resource use at the turn of the century.

VIII. CONCLUSION

We must act now. A decision too long delayed is a negative decision. Decision by default will place man's future in the hands of violent environmental forces. To avoid our writing our own epitaph, we must devise the means to mobilize the wisdom, science and energy of this nation and the world. We must cease wasteful man to man and man to nature conflict. We must dedicate ourselves to improving our understanding of things natural so that we, as present custodians of the land, may live in closer harmony with our environment. In short, man must revere his *eco*system more and his *ego*system less.

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Session on Causative Factors: THE PRAIRIE BORDER AND SUCCESSION

Session Moderator: **PETER SCHRAMM** Department of Biology, Knox College

Ecological Effects of Fire on Tallgrass Prairie

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INTRODUCTION

The site for this study was the University of Missouri Prairie Research Station. The tract was never broken for cultivation. It is a relic example of claypan prairies with impeded drainage which were formerly extensive on flat topography in east-central Missouri.

This paper summarizes certain effects of fire over an 11-year period which deal with shifts in community composition and with root system biomass in the upper profile. During this period several schedules were followed, always in early spring when soils were cold and wet. The schedules were annual burning, biennial burning, and fire applied every fifth year. All treatments were replicated four times on permanently designated plots.

THE INFLUENCE OF FIRE ON PRAIRIE

In an earlier paper (Kucera and Koelling, 1964) it was shown following five years of observation that grass densities tended to decline on those plots where litter accumulated in the absence of fire. In these plots there was a noticeable shift to greater population densities of several broadleaved types, primarily *Solidago* spp. and to a lesser extent *Aster* and *Helianthus*. These general effects were most significant on the flat, poorly-drained portions of the prairie, or where slight depressions or swales occurred. On plots burned annually production and densities of native prairie grasses were maintained at levels which were, in some cases 100 percent greater than those of control plots. On plots burned once in five years, deterioration of grass growth and vigor was observed, similar to that for fire-free plots.

Six additional years of fire observation have not essentially altered the earlier findings. A general stability of sparse grass cover is the result on control plots, with a concomitant high degree of prevalence of broadleaved species. Pertinent data are presented in condensed form in Table 1 for 10 consecutive annual burns, for two fires spaced five years apart, and for no fire during this period. It is noted that frequency values for grasses remained unchanged unlike those for composites, which followed more closely respective density trends. These effects may reflect basic differences in morphology and growth habit between the two taxonomic groups. Since no additional changes in species composition and relative densities were effected beyond the fifth year of observation, it would appear that litter accumulation causing community modifications is reached prior to this time. Under present environmental conditions which excludes grazing by large herbivores, a disappearance rate per year for dead standing crop and litter of 0.52 was determined. This value when applied to a logistics curve to determine proportionate parts of equilibrium time showed that 94 percent of steady-state conditions for litter was reached in five years. These relationships pose practical implications in fire management of prairie, and suggest that intervals of five years or longer between fires are ineffectual in preventing litter accumulation to stagnation levels. Thus, to avoid floristic changes and lowered plant production fire should be implemented before 90 percent or more of maximum residue is achieved. It is proposed that a three-year interval between burning is feasible to maintain grass dominance, as well as retain the species diversity typical of the native prairie community. Under present decay potential conditions, this interval allows for a litter development of approximately three-fourths of estimated accumulation for the equilibrium state. On a dry matter basis this proportion is equivalent to a mean value of slightly more than 400 g/M^2.

Additional evidence of fire influences in tallgrass prairie was shown by root data. On plots from which fire was excluded for five or more years, total root-rhizome biomass in the upper five centimeters of the profile ranged up to 39 percent less than on annually-burned prairie. Rhizomes were more severely reduced than roots. Twenty percent of the soil cores from control plots did not yield rhizomes, compared to six percent for fire plots. This difference is indicative of the significance of fire in maintaining high densities of big bluestem, a principal rhizomatous species.

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TABLE 1

Frequency and abundance values for grass, legume, and composite groups after 10 years of treatment.

GROUP	TREATMENT					
	No Fire		Annual Burning		Every 5th Year	
	F–%	A[1]	F–%	A	F–%	A
Andropogon spp.	100	13	100	20	100	11
Other Grasses	17	2	20	2	23	3
All Legumes	10	I	7	I	13	I
Aster & *Solidago* spp.	30	II	17	I	50	II
Other Composites	13	II	7	I	13	II

[1]Grass abundance is average basal area of crowns expressed as percent of sampling area; for legumes and composites values based on stem counts and expressed as density classes, I=1; II=2-10; III=11-50, in 0.5 M^2 quadrats.

Prairie Ecosystem Boundaries in North America

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Prairie, or temperate grassland was one of the largest natural communities in the Americas. In the United States there were originally 700 million acres and in Canada and Mexico possibly 275 million more, to make a total of nearly one billion acres. This then comprised about 22.5% of the continental land area north of Panama (excluding Alaska). The north to south extent is roughly 2,400 miles or over 30° Latitude. From central Oregon to the tip of the Prairie Peninsula in Ohio is roughly 1,700 miles. There is no acceptable method for detailed measurement of the periphery where grasslands contact adjoining communities but the total of boundaries could conceivably exceed 25,000 miles, equivalent to great circle circumference of the Earth. Figure 1, while not showing the smaller outliers, indicates the main body of North American prairie and its relation to adjoining biomes.

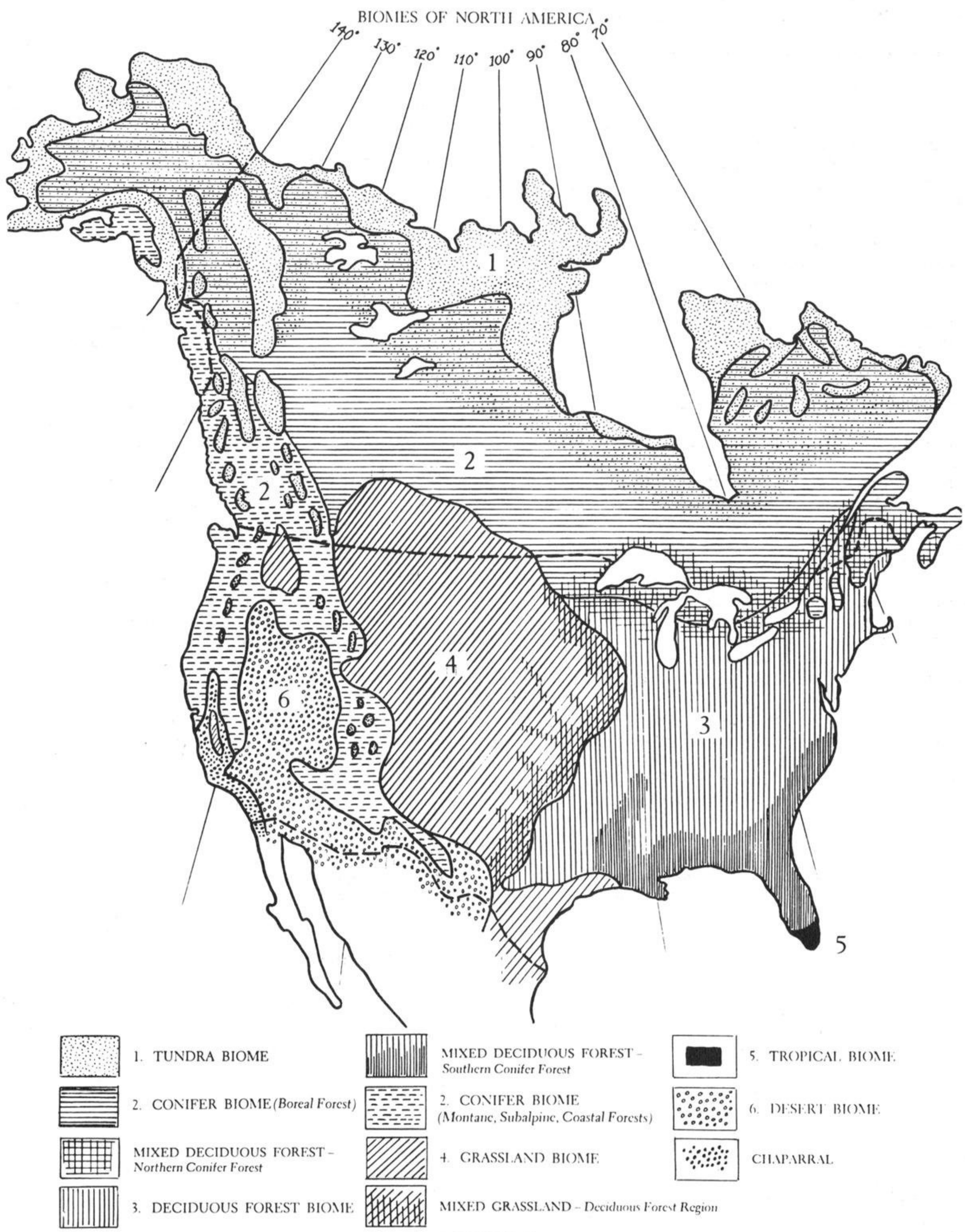

FIGURE 1

Major biomes of the United States and Canada (from C. J. Hylander, Wildlife Communities, by courtesy of Houghton Mifflin Co.).

Ecologists, commonly accustomed to thinking of a "net effect" of climatic factors, might first seek to hinge the whole explanation upon the functioning water economy at various edges of the prairie ecosystem. One might simplify this line of thinking by the truism: if there is *enough moisture* present to support trees, a *forest will develop*. However Figure 2 clearly shows that, in the center of the continent the lines of rainfall are nearly along lines of longitude. This is contrary to our usual observation that as one travels straight north he would cross successive bands of vegetation oriented in an east-west zonation. We soon find that there must be various causes which are locally effective in determining the position of prairie edges. The generalized weather map, Figure 3, has many lines in an east-west arrangement but does not strictly follow the expected change from prairie to forest as one travels from the Mississippi valley eastward. Thus, if we can accept the idea

PRECIPITATION REGIONS OF NORTH AMERICA

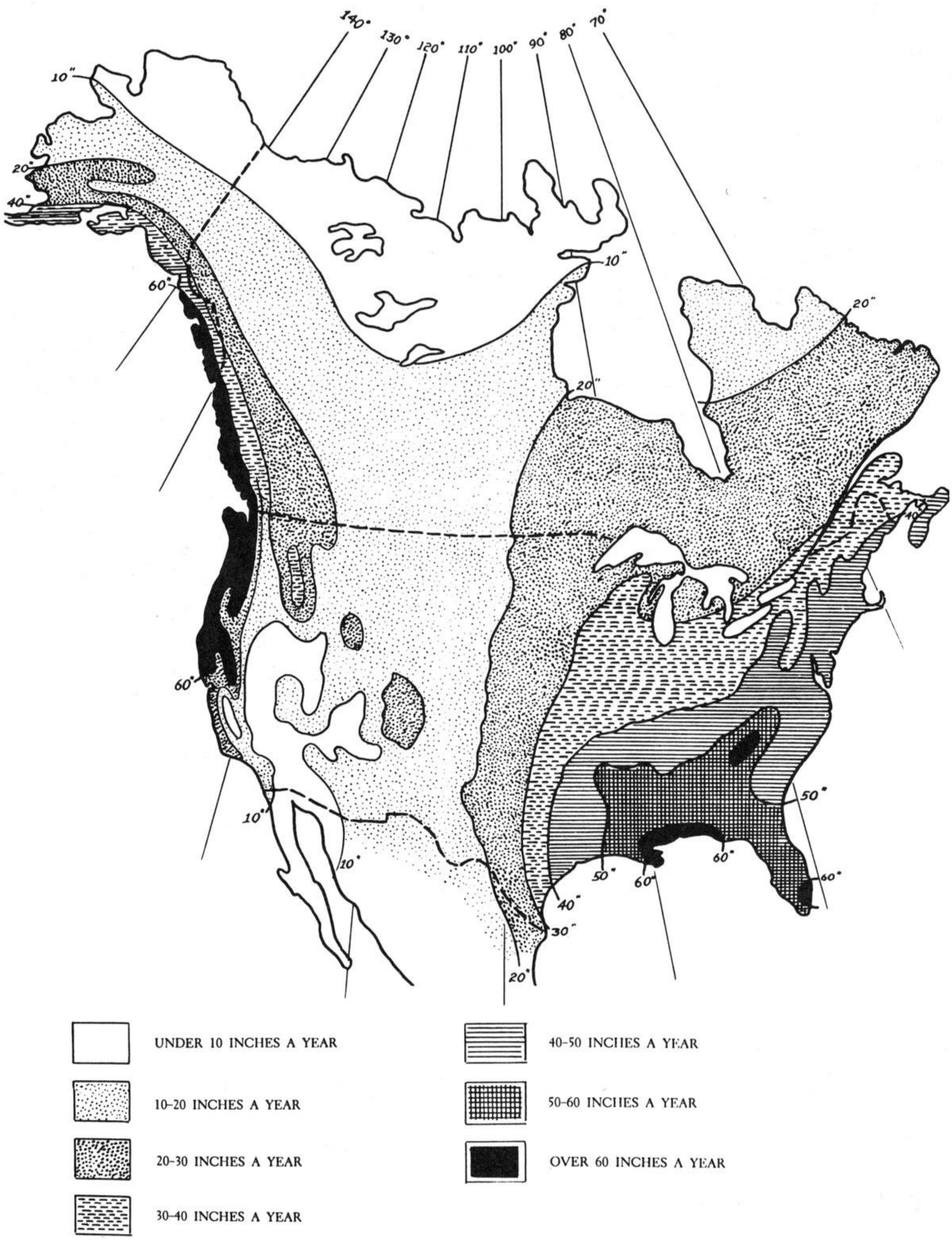

FIGURE 2

Generalized distribution of annual precipitation, by 10 inch intervals (from C. J. Hylander, Wildlife Communities, by courtesy of Houghton Mifflin Co.).

that the crucial factor may be different along various parts of the boundary, we can treat these special cases individually.

The discussion that follows will be an attempt to evaluate some of the local prairie edge situations as well as to consider a much more intricate problem, namely the modifying effects of fire. If the effort is worthwhile we can reach for yet another level of complexity, namely the whole interacting climate-soil-fire pattern of environmental controls.

As sketched in Figure 1, grasslands occupy the greatest fraction of the North American heartland. These grasslands form an inverted, irregular triangle. For convenience in discussion, the boundaries can be divided into four principal regions which are generally the western, northern, eastern and southeastern regions, to be presented in that order.

THE TEMPERATURE BELTS OF NORTH AMERICA

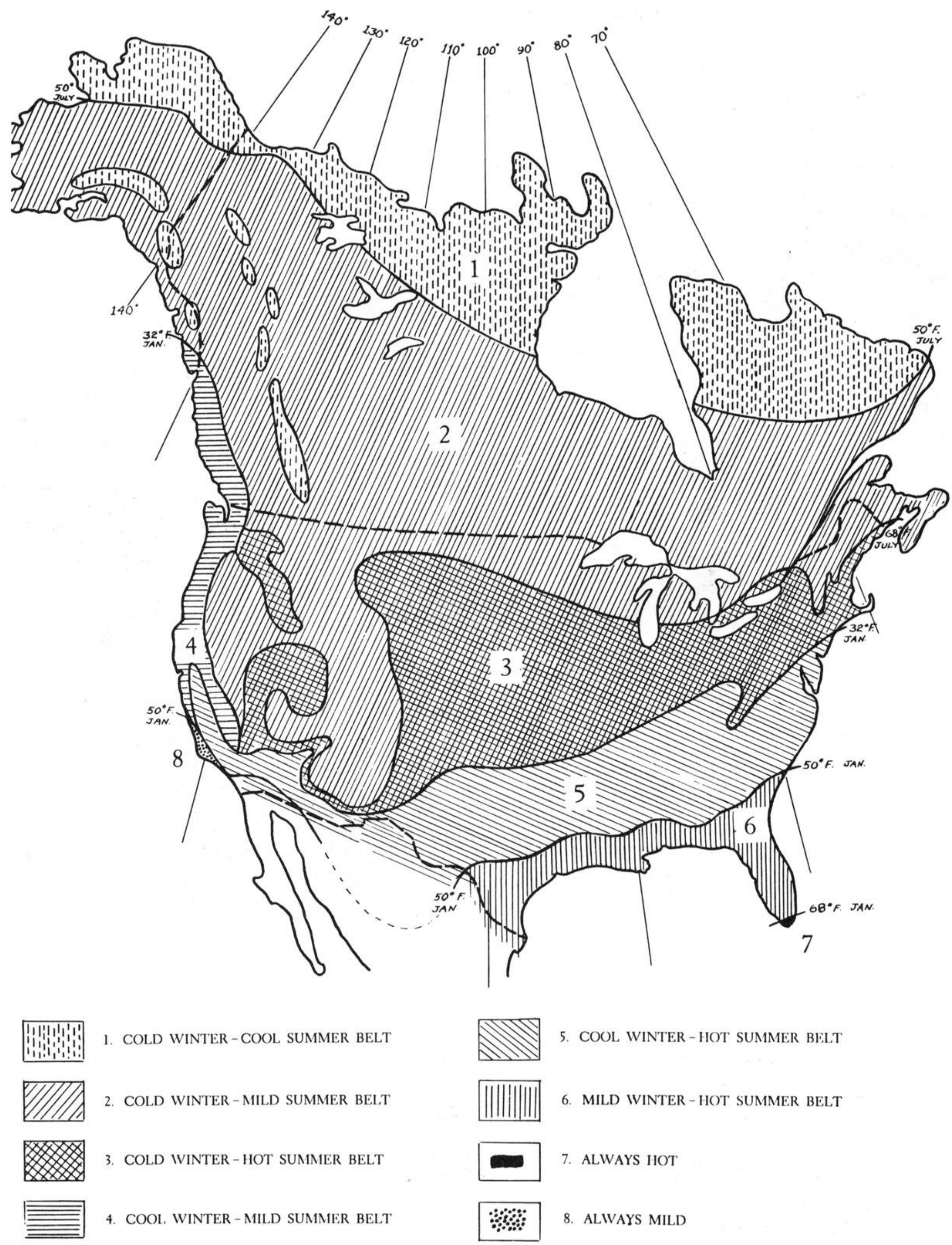

FIGURE 3

Generalized climatic regions with respect to seasonal weather patterns (from C. J. Hylander, Wildlife Communities, by courtesy of Houghton Mifflin Co.).

FIGURE 4
Deciduous Forest-Tall Grass Prairie tension zone at Galesburg, Illinois, Knox College Biological Field Station (Photograph courtesy of Oneita Fisher).

Rocky Mountains (Western Prairie Edge)

Many of us state glibly that prairies yield rather abruptly to montane forest as one ascends the foothills of the Rockies. While this is a plain statement and largely a true one, it can be restated with more precise expression. Development of montane forest is an attitudinal effect or still more fundamentally speaking, a climatic effect. This results from decline in temperature and increase in humidity (or rainfall) with increase in altitude. Still another consistent difference is a shortening of growing season. All these tendencies augur for a forest climate and, in this case, coniferous forest. Since the east slope of the Rockies is fairly steep the change in climatic factors is abrupt and vegetation types have fairly discrete lines. Ridges which stretch eastward into the lower foothills have pronounced topographic contrasts, of course. Their dry, sunny south-facing slopes are grassy, brushy, or with very open stands of ponderosa pine.

In short, the eastern foothills of the Cordilleran chain in North America also serves fairly well as a type line for western edge of the prairie. This produces little controversy among ecologists, unless it be for a small section in Wyoming where grassland is said to contact sagebrush or cool desert. However, it has generally been found that a definitive explanation of sagebrush is a troublesome task. Overgrazing, changes in water table, or ill-timed burning may bring about a heavy stand of sagebrush on what otherwise should be a rich development of grassland. It is probably wise to accept the grassland—sagebrush cool desert as the contact of two valid communities, at least provisionally. Further accumulation of data may help clarify this problem.

Aspen Grove Grassland (Northern Prairie Edge)

Along the northern edge of the prairie, in the Prairie Provinces of Canada, one might first expect contact with the wide boreal forest, prominent on the strongly glaciated Canadian shield. Instead there is a peculiar community consisting of scattered "aspen domes" in prairie. The soil type is generally fertile, black flat-land. Ecologists find this type to be so persistent that it must be taken seriously. However, the band of Aspen Grove Grassland is fairly narrow, seldom 50 miles in width, between pure grassland and northern coniferous forest.

Explanation of the causes of Aspen Grove Grassland (or "Parkland") is not easy. Possibly one of the best suggestions is that the short growing season begins to take its toll, as we reach higher latitudes. The brief summer works against either well developed prairie vegetation or deciduous forest. Consequently, in the zone of tension, aspen domes provide a suitable substitute for a typical forest ecosystem. It may be mentioned in passing that farmers control the size and check the spread of aspen and their brushy fringes by occasional use of fire.

The Prairie Peninsula (Eastern Extension of Grassland)

A broad wedge forms the contact of prairie with the Eastern Deciduous Forest. While the term "Prairie Peninsula" was first published by Adams (1902), intensive study and definitive proof followed shortly, by Transeau (1935). Save perhaps the work of Curtis (1959) and other ecologists at Wisconsin, we have done little to improve upon Transeau's study since his monographic investigation.

The Prairie Peninsula is a triangle with its points at approximately Fergus Falls, Minnesota; South Bend, Indiana; and Bartlesville, Oklahoma. Following the original detailed description these limits were quickly recognized by Weaver and Clements (1938), Shelford (1963), Braun (1950) and others. Kuchler's (1964) map sketches virtually the same idea but reverts to a more cautious viewpoint by referring to Tall Grass Prairie—Oak Savannah mosaic. While this is fully defensible, it would appear to be almost too non-committal. In fact, such an attitude seems faintly influenced by the recent history of the Peninsula area wherein white man's practices greatly change the effective environment. In Kuchler's map, as well as those of Curtis (1959), Daubenmire (1936), and possibly others, the grassland touches Oak-Hickory forest over the greatest extent. However, there are places in Minnesota, Wisconsin, Indiana, and Ohio in which there is direct contact with either Beech-Maple or Maple-Basswood Forest. These may require somewhat different explanations.

As just stated, the longest prairie-forest contact is with Oak-Hickory. Where there are spots or islands surrounded by grassland, the vegetation and fuel-type can well be called a fire-prone situation or fire environment (Komarek, 1964). The plains Indians used fire for a number of purposes, possibly extending back 8,000 to 10,000 years (Wells, 1965; Sauer, 1952). Furthermore, we can assume that lightning could have caused fires, occasionally. In primitive times and in combustible, fire-prone areas such as the Prairie-Oak-Hickory environment, fire would carry far. If the time interval since the last fire was great, there would have been considerable accumulation of litter and thus a hot fire. In turn, fairly large trees, venturing into the grassland, could be killed or badly set back. Figure 4 suggests the ample biomass (i.e. fuel) production in the tall grass prairie vegetation. In this way, long-time repetitive fire occurrence would fix the general limit of forest and prairie boundaries. Under this concept recurring fire is considered to be a regular evolutionary force, particularly for the prairie dominants, and they would be expected to adapt accordingly.

On the contrary, a plausible interpretation of the prairie contact with maple-basswood or beech-maple forest presents greater difficulties. These mesophytic forests reach the grassland in Minnesota's Big Woods (Daubenmire, 1936) and in portions of Wisconsin according to Curtis (1959). There is also considerable contact of moist forest and grassland at the eastern extremity of the Peninsula and around the smaller "islands" in Ohio. In these areas fire was probably less frequent and inclined to be catastrophic in effect. Although annual grass biomass production is greater here than in oak-hickory forest or tall grass prairie, the incidence of severely dry fuel condition is lower. Thus natural fires would not have a likelihood of spreading very far. The more rare catastrophic fire does not serve as a good evolutionary force. In lieu of a homeostatic relationship between prairie-fire-forest, we perhaps prefer to consider climate-soil causes for the edge of mesophytic forests.

Gulf States Contact (Lower Eastern Edge)

From about Bartlesville southward to the Gulf Coast at the Texas-Louisiana line there is a slightly different problem than that of the point of the Peninsula, although it should be immediately emphasized that the main picture, and most of the comments of the preceding section, still apply.

Along this portion of the prairie boundary there is a longer growing season and consequently the communities involved require a greater moisture supply to serve their needs during an additional three to four months of activity. Another complicating factor is that variation in quality is great, along this sector. This tends to give streaks and spots of forest perhaps even more pronouncedly than in some of the northern states. Oak savannah is often in contact with the prairie in Oklahoma and upper Texas. Parts of central Texas have cedar breaks or oak savannah, again. Coastal portions of Texas and Louisiana support pine woods, which normally grows in an open stand.

All these comments should suggest another fire-prone situation. Consequently, although the soils and growing season is much different, it can be said that the occasional natural fire had much to do with locally determining the forest-prairie boundary. Additional comments on fire ecology are offered in the next section.

Ecological Adaptations to Fire

Historic accounts of use of fire amply prove that the plains Indian understood its services in behalf of brush control, easier travel, and to lure game by improving the forage or at least making grazing an easier process. We therefore know that Indians burned large areas in the central prairies but perhaps even more often along the eastern margin where brush and trees constantly tended to encroach. Komarek (1964) reports that there are from 40 to 50 thunderstorms per year in the eastern prairie areas. Figure 5 gives illustrative data on the seasonal distribution of lightning and man-caused fires in a grassland area of Wyoming. Long continued natural fire guides

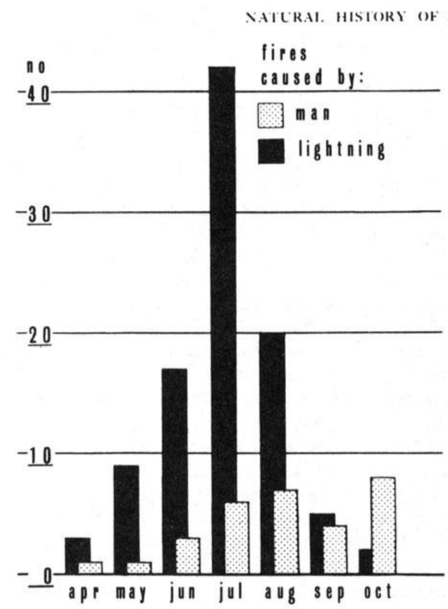

FIGURE 5

Graph showing relationship and occurrence of lightning and man-caused fires, primarily in grasslands. Data from Laramie Peak Division, Medicine Bow National Forest and Thunder Basin National Grasslands, Douglas, Wyoming, 1960.

evolutionary change in two ways. First, fire sensitive species are eliminated or strongly suppressed. Second, fire resistant variants are selected and favored for survival, by virtue of this advantage.

One of the most effective fire adaptations is simply the shielding of critical points such as apical and bud meristems. The greatest heating effect of fire is in the air several inches or feet above ground. Herbs with underground rhizomes or deeply located crown buds are particularly at an advantage. Lemon (1949) found that important southeastern United States grasses had leaf meristems 1.5 inches below the soil surface. Rhizomatous goldenrods also have buried buds. Shrubs such as sumac also spread by underground rhizomes, of course. Brushy species of oak sprout vigorously from surviving underground parts. On the other hand, typical plants of the mesic forest are usually killed by light or moderately intense fires (Cooper, 1961).

Another set of adaptations relate to the timing of reproductive or regrowth processes in the annual cycle of biologic events. Careful studies of monthly carbohydrate storage (Weinmann 1948, 1952) have been helpful in learning when a fire is harmful and when regrowth from existing reserves is to be expected. As a generalization, early spring fires have often been destructive, while late summer burning or winter fires cause only a mild nutrient drain. It could even be said that an ideally timed fire renders the same physiological service as decay of litter. Acceptance of this viewpoint helps to explain the normal nutrient turnover in nature and assists one in visualizing the mechanics of ecosystems which include a fire environment.

Discussion and Conclusions

In modern urban backgrounds, so many of us have grown up to feel that fire is a destroyer that it is sometimes difficult for a scientist to overcome this facet of our traditional background. It is an amazing paradox that many primitive peoples have a clearer view of the usual role of fire in nature. Another reason we underestimate the functions of natural fire is that, by contrast with other leading environmental factors, it is not an annual nor even regular event. However, modern ecologists are becoming more willing to recognize the controlling influence of occasional phenomena such as glaze ice storms, hurricanes, or floods. If such events, singly or in concert, recur often enough to check back an otherwise large species population then they become a *normal* component of an ecosystem.

One of the main interests of ecologists is the explanation and interpretation of community boundaries (discontinuities) in either time or space. The task is simpler in a small ecosystem or, for example, the line where land meets the ocean (Gulf Coastal Prairie of Texas). But the prairie ecosystem, comprehensively considered, is one of our major North American vegetation types. Extending through 30° Latitude and about 35° Longitude, we can expect that wide environmental differences are included. And yet most experienced scholars seek to explain a sort of net or integrated effect which is essentially the same throughout, though caused by varying combinations of individual factors. Unfortunately, this may lead to an assumption that the whole pattern rests upon a concept of "equivalent climates." This would not harmonize with the ecosystem or holistic viewpoint. Climate, interacting with vegetation, animal life, soil, and important irregular factors such as fire must be our guiding theory. Reduced to simplest form we might say that the climate-soil interaction is ruling save where modified by fire.

The, by now superfluous, argument about whether fire is "destructive" or not can be disposed of readily. Fire is destructive where it is severe and infrequent, particularly in a completely unadapted (to fire) vegetation type. In such an area both plants and animals suffer and the community may be thrown back to an early successional stage. On the other hand, if fires are set fairly often, about two to five year intervals, by storms or indigenous man, fire is not destructive. In such a situation the dominant species will be fire resistant (sometimes even fire-dependent) and the whole fauna and flora will be adapted to evading or persisting through periodic mild burning. So far as plants are concerned, the principal requirement is that burning be properly timed to fit in with the cycle of growth, food manufacture, and dormancy. This must allow the normal metabolic processes of food production and completion of reproduction.

Finally, it would appear that the main segments of the prairie boundary are:

(1) Rocky Mountains, where altitude quickly creates a forest environment,

(2) Aspen Grove Grassland, a transition to boreal forest, probably caused by short growing season,

(3) Prairie Peninsula, where soil may limit the prairie at contacts with mesic forest but fire seems effective in fixing the edge of Oak-Hickory forest or Oak Savannah, and

(4) Gulf States or lower eastern edge appears to be controlled by fire since the fuel and droughty soils often make an ideal fire-prone environment.

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Edaphic Factors in the Prairie-Forest Border in Wisconsin

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The tall-grass prairies were a striking feature of the original landscape and for over a century and a half explorers, settlers, botanists, geographers and others have joined in the discussion of the possible causes of prairies vs. forest cover. The literature is far too extensive even to summarize here, but the excellent review and summary on "The Prairie Peninsula" by Transeau in 1935 has not been improved upon as a general statement of the problem and its historical background. Now, ⅓ of a century later, a great increase in data reported in many scattered papers, from soil minerology to phytosociology to microclimatology, coupled with the fantastic growth in instrumentation and data processing capability, should make possible a wide-ranging and penetrating reassessment, which apparently is now awaiting a new major effort. It will be no small project and probably will require a team effort over several years which should include experimental studies of several types to explore the various hypotheses. Probably it should be tied in with the I.B.P. Grasslands Project, which appears now to be centered more on the High Plains range lands. This symposium should serve as a spur to further efforts in this line.

Transeau's classic summary emphasized that several major factors are involved, among them climate and especially moisture stress, fire, grazing and browsing, and edaphic factors. Certainly all of these play a part, interacting in various ways and varying in their relative importance on different sites. Dryness of climate certainly plays a major role in grasslands as a whole, but especially along the prairie border, and even in the whole "Prairie Peninsula" which McComb and Loomis (1944) called "Sub-climax Prairie," it is not a simple climatic factor but an interaction of climate, microclimate, topography and soil which produce varying frequencies and intensities of drouth conditions which thereby inhibit tree growth. Fire certainly has played a role in at least delaying advancement of forest along much of the forest border in presettlement times, and here also time itself becomes a factor in the history of post-glacial vegetational change. Several aspects of the edaphic situation have been mentioned by various authors and some are self-evident, e.g. very steep or coarse or shallow soils are obviously more droughty than deep, level, medium textured soils and concommitantly prairie species as a whole are more drouth resistant than forest. Other edaphic factors may include pH, mineral nutrients, toxic minerals, æration, physical characteristics of soil, and perhaps indirectly the microbiology of the soil. Unfortunately with so many interacting variables in field conditions it is practically impossible as yet to separate them and assign relative weights to each on different specific sites. One basic principle of ecology of course is the interaction of factors, about which there is as yet a great deal to be learned. As Transeau pointed out so well, prairies existed on excessively drained and on poorly drained as well as on mesic sites, on very fine clay soils as well as silt loams and sands, on a fairly wide range of pH, parent materials, and fertility levels, as well as in precipitation ranges from about 20 – >40"/yr. Hence the challenging question, what, if anything, do prairies have in common which makes them prairies?

My own interest in prairies goes back to boyhood on a Northern Illinois farm but professionally it consists of about 20 years in which my research interests ranged between forest and prairie in the border areas of Northern Illinois and Southern Wisconsin and even extended to Tennessee and Mississippi barrens and prairies. Originally interested in floristics and phytosociology, I have become more and more impressed by certain edaphic relationships, some of which were included in a paper 10 years ago on "Prairie Remnants in Southeastern Wisconsin" (Whitford, 1958), and others which I have been trying to pin down in more recent work, as yet unpublished.

In my early study I surveyed the available prairie remnants, totalling over 60 sites, in two counties adjoining Lake Michigan in Southeastern Wisconsin. These represented an island of original prairie interspersed with oak openings and scattered groves, which once covered nearly half of these counties, surrounded by forest and well within the region of forest climate. I concluded that these prairies had persisted partly because they occupy a nearly level, heavy calcareous clay soil which is saturated in spring and poorly ærated but which bakes dry with large deep cracks in summer. The extremes of seasonal moisture and the physical effect of soil shrinkage on drying are more damaging to trees than to prairie species. Both the driest and the wettest of these sites had a tendency toward wet prairie types in the spring flowering species and to more mesic to dry-mesic types in the late summer and fall species as judged by J. T. Curtis' prairie continuum (Curtis, 1955). The interspersed and surrounding groves and oak openings were on coarser soils and/or steeper slopes with better drainage and æration. These differences may of course affect tree growth indirectly, by controlling the micro-flora of the soil, as well as directly through æration and moisture extremes. Also the relatively high pH (ave. 7.2 with nearly ½ the readings at 8.0), along with unusually low P and high K compared to typical forest soils of the area, may have direct or indirect effects or both. Poor æration was shown by gley horizons at less than 30 inches in ⅓ of the profiles and at least some gray mottling of subsoil within 36 inches in over 85% of these prairie sites.

A few years later I had an opportunity to survey prairie remnants in the Black Soil Belt of Northeastern Mississippi, which has long been noted as a distinctive area, though more recently discounted by a geographer as a "myth" (Rostlund, 1957). Original survey records and pioneer accounts show that a considerable extent of open grassland and savanna existed on a narrow crescent across Alabama into Northeastern Mississippi and a bit into Tennessee. Again this prairie belt was in a forest climate of over 40" average rainfall, again it was on flat clay soils broken by forest on steeper slopes and on flood plains, again it was on a calcareous substrate, in this case derived from the soft Cretaceous Selma Chalk formation. The subsoil is highly impermeable and alkaline and the surface soils black but highly colloidal in behavior, very sticky when wet, and cracking open in drouth, though they proved quite fertile for cotton farming and very little native vegetation is left. Interestingly the appearance of scattered spreading old oaks on the border is very similar to that typical in Illinois and Southern Wisconsin.

Most of you are aware that the major prairie regions of Illinois, especially the "Grand Prairie" region designated by Vestal (1931), lie on flat, poorly drained soils relatively high in clay content at least in deeper layers, although often with upper layers of lœss. A survey of the distribution of geological and soil maps compared to major prairie areas of Wisconsin shows again that most of the prairies existed on calcareous clay loams or fine silt loams derived from calcareous till and commonly overlying limestone at depths of 6–10 feet or less. I am convinced that this is not mere coincidence, however prairies also existed to a lesser extent on sands and a variety of other soil types in central and eastern Wisconsin, complicating the total picture. I have gathered considerable data on prairie remnants in these areas in recent years but have been prevented by administrative duties from completing the study as planned. Part of the problem, I admit, is in the complexity of interacting variables. Part of the problem lies in the nearly total lack of data on seasonal soil moisture regimes for various sites and a similar lack of experimental data on growth and survival of prairie versus forest species under these different conditions of soil moisture, pH and nutrients. Such data will require more time and expense than one person is likely to have for the problem in the immediate future but should certainly be worth pursuing further.

From the practical standpoint general observation would indicate that soils alone are not usually limiting factors in any absolute sense, in that prairie soils support transplanted trees and may be invaded when drained or otherwise disturbed, while on the other hand forest soils are readily invaded by many prairie species when the forest has been cleared. However I have yet to see a good true prairie soil site invaded by trees without disturbance by man, nor yet a forest site become a true prairie in spite of repeated cutting or burning, although it is true that with diligent effort and management a reasonable simulation of prairie can be established on almost any soil type. Quite possibly a major factor is the competition plus the reaction of each vegetation type upon the soil, so that either when well established tends to maintain itself to the exclusion of the other. This of course is in our favor in attempts to establish or re-establish prairie, for the longer and better we manage it the less management effort it will require as it becomes a more integrated and competitive community.

As to the role of fire in the original prairies, there is no doubt that it was a frequent factor on much of this area, but whether it was cause or effect is less clear. Certainly the dry grass litter, open to the wind, burned more readily and hotter than leaf litter shaded by trees and protected from wind; certainly also most prairie species have evolved a high tolerance to dormant-season fires and even are benefited in vigor and flowering by the sudden release of nutrients and removal of shading litter. However, the early descriptions of so-called "brush prairies," coupled with observations of sprouting on frequently burned marginal areas, lead me to doubt that fire alone converted forest to prairie. Obviously, sites which are edaphically droughty, even if only in certain seasons, are more vulnerable to fire than less droughty sites so that even if considering fire one must also consider edaphic factors. Fire is of course a useful management tool in prairie establishment by helping to prevent establishment of woody species as well as reducing competition from bluegrass and weeds and by its well-documented effect in stimulating seed production of most prairie species.

In conclusion, increased knowledge of the edaphic relationships of border prairies should be an aid in selecting the most advantageous sites for prairie restoration, and also prairie restorations can help to serve as a test of edaphic factors in relation to prairie species and the problems of maintenance.

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Competition Between Forest and Prairie Vegetation in Twenty Years of Secondary Succession on Abandoned Land in Ogle County, Illinois

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INTRODUCTION

The study area comprises approximately 30 acres in the center of section 33 of Rockvale Township (T 34 N., R 10 E.), Ogle County, Illinois. The site is adjacent to Illinois Route 2 and extends westward from the highway for about 2200 feet. It is of varying widths because of the hilly terrain and the nature of the clearing of the original forest. In elevation it rises from 700 feet at the east end near the highway to 830 feet at the west end. On a ridge at the extreme northwest corner the elevation is 860 feet. The area is almost entirely sloping, with drainage by old gully channels.

The site first came to our attention in 1951, when Northern Illinois University acquired the Lorado Taft Field Campus across the Rock River to the east. The first detailed study of the site was made in 1958, another in 1959, and the most recent in 1967. Frequent visits for observations have been made to the area at other times from the early 1950's to the present.

The area is unique in its history. To our knowledge, no studies in this type of situation have been made in Illinois and few have been reported from elsewhere that involve abandoned pastureland under similar circumstances.

Prior to 1835, the uplands to the west of the Rock River were tall grass prairie with occasional oak groves. The prairies graded into a xerophytic oak-hickory type forest on the slopes approaching the Rock River. There was a change to a more mesophytic type as the lowlands were approached, with red oak, basswood, and maple dominant. The narrow floodplains of the Rock River were covered with typical flood plain forests and swamps.

The area had undoubtedly been subjected to frequent fires, both before settlement and after. In 1842 and in 1843, fires were reported sweeping from the Mississippi on the west all the way to the Rock River (Kauffman 1909). The fires maintained the prairie, contributed to the oak composition of the groves, and aided the maintenance of prairie openings on the dry knolls and exposed hillsides, many of which persist today.

In 1833, Rockvale Township was surveyed by the son of Alexander Hamilton. Section 33 was claimed by a settler in 1835 and in that same year the first house was built in the Oregon area. The road along the river was laid out in 1837. Agricultural use of the field must have begun by then.

The site was ideal from the standpoint of a forest-oriented settler from the eastern states. The river provided a transportation route and fish in abundance. Copious freshwater springs flowed from the hillside, continuing to this day. The forest provided the lumber, fuel, furniture and tool materials so essential in that day. The settlers cleared the land with the least slope for farming and used the steeper parts for forest products and grazing.

Our study field was probably heavily cropped for many years, but sometime before 1900 it became so badly eroded that it was converted from cultivated crops to pastureland and hay meadow. We know that light pasturing took place from 1936, when the land was purchased as a country estate by the Strong family, and it stopped in 1948, when a house was built for a relative at the north edge of the area. There has been no disturbance by domestic animals since 1948 and very little by man.

The adjacent forest, both to the north and to the south, was severely decimated in the 1890's by cutting, drouth, and insect damage (Kauffman 1909). After the Strong family purchase in 1936, the forest was not disturbed except for the sale and cutting of some walnut trees. The relatively level uplands to the west of the field have been tilled continuously by farmers from settlement to the present time.

Geologically, the area is covered with a thin Illinois glacial drift with some lœss on top, over Galena dolomite and Platteville limestone. There is a small gravel pit in the field and an old limestone quarry at the south central edge. St. Peter sandstone is beneath the limestone and it outcrops in some places nearby.

Soil types in the forest to the south are Sogn and Haymond silt loams, shallow and not very productive. On the lower levels are deeper soils deposited from erosion of the areas above. The silt loam soils that the first settler plowed after clearing the field were all washed away and today there is no evidence of any topsoil anywhere on the field.

EARLY APPEARANCE

The area under consideration is referred to as the Strong Field and has been a part of an estate called The Stronghold since 1936. When viewed from the bluffs across the Rock River a quarter of a mile away, the field had the appearance of an open pasture in the early 1950's, with the exception of a strip of trees that had grown up in an old gully that cut through the field from west to east. An early photo reveals that in 1903 the field was apparently a pasture with only a few small trees in the gully at that time. In over a half century the original trees had grown to maturity and many others had entered the area.

However, in the early 1950's only a few small trees were in evidence in the open pasture when seen from a distance. Upon close examination, it was apparent that seedlings were becoming established in considerable abundance. These were mostly trees with windborne seeds, such as box elders and elms. There was a scattering of trees brought in by birds. The various woody plants found in the field up to the present time are listed in the Appendix (Appendix I and II).

The most conspicuous feature of the field in the early 1950's was the abundance of Kentucky blue grass throughout the open areas. Scattered through this typical pasture setting were various species of farm weeds, plants escaped from cultivation, and a few species of native prairie plants. Gradually, since that time, additional species of prairie plants have become evident. As the tree population has increased, so has the presence of forest type herbaceous plants. The various herbaceous species identified to date are listed in the Appendix (Appendix III, IV and V). A more detailed discussion of special situations follows.

PRESENT SITUATION

There has been no uniform development of vegetation in the Strong Field during the twenty years from the cessation of pasturing in 1948 through the summer of 1968. Therefore, aspects of vegetational development pertinent to the title of this report will be discussed in various habitat situations.

Gully vs. Slope

The gully mentioned earlier has long been a conspicuous feature of the field. By the start of this century it was probably six to eight feet deep in places and varying in width from a few feet to about fifty. After the development of trees and an undergrowth of herbs and shrubs, erosion ceased. A study of the larger trees by increment borer has revealed that most of them became established between 1914 and 1933, although a few were older. A survey of the trees in the gully in 1958 revealed 15 species with a total of 551 trees. The box elder *(Acer negundo)* comprised 53.5% of the population of trees. The walnut *(Juglans nigra)* was next with 17.1% (Table 1). Because of the rather dense shade, typical prairie plants were absent from the gully area.

TABLE 1

TREES OF STRONG FIELD

	Number in Gully Survey of 1958	*Number in Quadrats Survey of 1958*
Acer negundo	295	64
Prunus americana	1	14
Ulmus rubra	35	53
Ulmus americana	18	2
Crataegus sp.	11	18
Juglans nigra	95	55
Carya ovata	15	26
Quercus velutina	9	47
Malus ioensis	16	15
Populus sp.	17	6
Ptelea trifoliata	23	
Prunus serotina	10	8
Celtis occidentalis	6	4
Totals	551	312

On the slopes of the remainder of the field, however, prairie plants were conspicuously scattered through the basic growth of *Poa pratensis*, where they competed with a variety of introduced weeds and with an increasing number of tree seedlings.

In 1959, a quadrat study was undertaken along the north side of the field in an area where trees were entering most rapidly. A quantitative analysis of competition between woody and herbaceous vegetation was desired. Six quadrats, of 100 square meters each, were analyzed in detail. The species of trees in these quadrats are indicated in Table 1. The sizes of the trees are indicated in Table 2. Of a total of 312 trees found, only two were over 12 feet in height at that time.

TABLE 3

Herbaceous plants of six quadrats. Data of July, 1959, after eleven years of development.

Species	Quadrat 1	2	3	4	5	6	No. of quadrats
Poa pratensis	x	x	x	x	x	x	6
Plantago major	x	x	x	x	x	x	6
Aster sp.	x	x	x	x	x	x	6
Ambrosia artemisiifolia	x	x	x	x	x	x	6
Lactuca sp.	x	x	x	x	x	x	6
Erigeron annuus	x	x	x	x	x	x	6
Mellilotus alba	x	x	x	x	x		5
Cirsium sp.	x	x	x	x	x		5
Potentilla arguta	x	x	x		x	x	5
Solidago sp.	x	x	x	x	x		5
Solanum carolinense		x	x	x	x	x	5
Prunella vulgaris		x	x	x	x	x	5
Mellilotus officinalis	x	x			x	x	4
Asclepias verticillata	x	x			x	x	4
Taraxacum officinale	x	x	x		x		4
Medicago lupulina		x	x		x	x	4
Andropogon scoparius	x				x	x	3
Rudbeckia hirta	x	x	x				3
Euphorbia corollata	x	x	x				3
Sanicula sp.		x	x	x			3
Carex sp.		x		x	x		3
Trifolium repens		x	x	x			3
Tragopogon pratensis		x	x			x	3
Hypericum perforatum					x	x	2
Cirsium arvense		x				x	2
Phleum pratense		x	x				2
Dianthus armeria				x	x		2
Antennaria neglecta				x	x		2
Verbascum thapsus				x		x	2
Physalis sp.				x	x		2
Anemone cylindrica		x					1
Desmodium illinoense						x	1
Rumex altissimus				x			1
Teucrium canadense		x					1
Oxalis stricta			x				1
Amphicarpa bracteata		x					1
Verbena urticifolia				x			1
Seteria glauca			x				1
Tradescantia ohiensis			x				1
Panicum sp.					x		1
Convolvulus arvensis					x		1
Verbena stricta					x		1
Achillea millefolium					x		1
Apocynum androsaemifolium					x		1
Physalus virginiana						x	1
Total species	16	27	24	19	27	19	45

TABLE 2

Summary of heights of trees in quadrat study of 1959. (Number of trees of each height category is shown for each quadrat.)

Height in feet	0-3	3-6	6-9	9-12	15-20	20+	Total no. trees	No. per m^2
Quadrat 1	47	8	1	1			57	0.57
" 2	38	14	5	2	1		60	0.60
" 3*	20	9	2	3			34	0.34
" 4	40	13	3	3		1	60	0.60
" 5**	63	15	4	2			84	0.84
Totals	208	59	15	11	1	1	295	
% of total	70.51	20.0	5.08	3.73	0.34	0.34	100.0	
Quadrat 6***	1	14	2				17	0.17

Note: All quadrats were 100 square meters in area.

*A high concentration of sumacs, 50 stems in all, occupied much of the area. These were not included in the tree count.

**This quadrat was not in the same line as the others. It was located at the edge of the oak forest to the north and contained a high concentration of young black oak trees.

***This quadrat was in the center of an area that had been sprayed to eliminate Canada thistle. The spraying also killed most of the woody plants. Of the 17 specimens, 16 were box elder and one was crab apple. The dead stalks were not reported.

The herbaceous plants of these same six quadrats are listed in Table 3. Of a total of 45 species identified in the quadrats, 16 are of foreign origin. In the entire field to date, only 21 species of foreign origin have been noted. These are listed in the appendix as naturalized or introduced (Appendix III). It is assumed that nearly all of the plants of this category were holdovers from the early days of agriculture and pasturing. Probably none have entered the field in recent years.

Twenty-four of the 45 quadrat species are native plants of prairies or open areas. To date, 33 species of this group have been found over the whole field. Some are of recent invasion (Appendix IV).

Only five plants typical of forests were found in the quadrats in 1959 and four of these were in only one or two quadrats and not abundant. To date there are 12 species in the field that are typical of forests. Most are of recent entry. A notable plant of recent discovery in one of the quadrats is the broad-leaved twayblade *(Liparis lilifolia)*. This orchid is frequently found in secondary succession forest development (Appendix V).

Lowland vs. Upland

Because of the slope of the land, as noted previously, there is a marked difference in habitat characteristics between the lower ground at the east end and the higher ground at the west end of the field. The lower ground has more moisture, receiving runoff from the upper areas, and has a deeper soil because of less erosion and some deposition from above. The differences in environmental factors are evident in the appearance of the vegetation. In the lower third of the field, the trees are more numerous, of greater size, and of more species. There is a corresponding decrease in herbaceous vegetation. It is evident that the future of the area is forest development.

On the upland the trees are smaller and more widely spaced. They are mostly box elder, elms (*Ulmus* sp.), and thickets of plum (*Prunus americana*). Bluegrass is here most persistent, but it has been invaded by various prairie forbs. There is little evidence of prairie grasses except in some isolated spots. These will be discussed later. The future of the upland is in doubt, but it is likely that a prairie can develop only with the help of fire, spraying, or clearing to reduce competition from woody plants.

Effect of Forest Edge

The entire field is surrounded by woody vegetation. To the north and the south, the original deciduous forest exists in a fairly intact condition, in spite of decimation in the 19th century. To the west and east, old fence rows have grown up into dense stands of trees and shrubs. Some of the older of these have provided an abundant seed source for invasion of the field by wind- and bird-carried species. Extensive farmlands to the west have provided few seed sources for herbaceous plants other than weeds.

The forests to the north and the south show an interesting contrast in their effect upon the Strong Field. The dominant tree in the forest at the north edge of the field is the black oak *(Quercus velutina)*. Young black oak trees are growing in a dense stand extending fifty feet out from the ends of the branches of the parent trees, but few are found beyond this narrow band. Only an occasional oak of any species is found in the central areas of the field. The shagbark hickory *(Carya ovata)* and the black walnut have also invaded the field from the forest to the north, but seldom beyond 100 feet.

The forest at the south edge contains numerous mature black walnut trees. Young walnuts are conspicuous by their presence in the border area along the south side of the field. Very few of the dominant white oak of this forest have started to grow in the field.

Conspicuous ecotones are developing on all sides of the field, in each case dominated by woody species from the adjacent border and populated abundantly by fruit-bearing trees, shrubs, and vines. It is obvious that prairie development in these areas is unlikely.

Prairie Grass Development

In only two small areas of the field has there been any conspicuous development of native prairie grasses.

At the highest elevation in the field, on the side of a gravel ridge topped by a fringe of black oaks, there was a good stand of tall grama-grass *(Bouteloua curtipendula)* in the 1950's. At one end of the ridge a small pit had been opened for the quarrying of gravel. Along the edge of this pit and also under the fringe of oak, the smooth sumac *(Rhus glabra)* appeared. Gradually the sumac extended itself by vegetative reproduction until in a few years the grama-grass was completely overgrown. Today the grass has nearly disappeared in a dense clone of sumac, which in turn is being invaded by walnut seedlings, probably planted by squirrels in the shade of the sumacs. As seen in another similar place in the field, the sumac will eventually be replaced by a grove of walnut trees. Thus succession proceeds, but at the expense of the prairie species.

In a bowl-shaped depression near the head of the main gully, another prairie species has become established. About 15 years ago, in a bluegrass area with a few scattered box elders and plums, there appeared a few small clumps of Indian grass *(Sorghastrum nutans)*. Each year the clumps produced seed and their number increased gradually. Today, the Indian grass dominates an area of about one-half acre. But here also there is woody invasion and competition. The large-toothed aspen *(Populus grandidentata)* has extended from the margin into the center of the area by shoots arising from extensive root systems. In 1967, an attempt was made to eliminate this competition by pulling the aspen shoots, which had reached a height of several feet. Since this effort, other shoots have appeared. Since the aspen grows very rapidly, it is evident that it will overgrow the prairie opening of Indian grass unless it is completely eliminated. This is now under consideration.

Effect of Spraying

About 1955, a small area of the field was sprayed with chemicals to eliminate a stand of Canada thistle *(Cirsium arvense)*. The treatment was only partially effective, for the thistle was still present in 1959, but it has since disappeared. However, many other plants were eliminated, especially the woody ones. In the quadrat study of 1959, one quadrat was located in the sprayed area. The results of identification of woody plants are indicated in Table 2. Five quadrats in an undisturbed area of the field contained from 34 to 84 trees in each 100 square meters. There were only 17 trees in the sprayed quadrat, number 6 in the table. Sixteen of the trees were small box elders.

The scarcity of trees in this area has persisted to this day. The development of a prairie aspect is quite evident, with goldenrods and asters being conspicuous in the autumn. Little blue-stem grass *(Andropogon scoparius)* is present, but not abundant. Perhaps this accidental demonstration has shown an effective way to assist prairie development and deter the growth of woody species.

DISCUSSION AND CONCLUSIONS

The progress of succession is the resultant of all the forces operating. Northern Illinois is located in a transition zone between the prairie biome and the eastern deciduous forest biome.

Gleason (1927) pointed out the conflicting forces at work in this region. The climate favors the forest, except in drouth periods. The physiographic processes at work in degrading the hills and broadening river valleys favor forests, as the woody species readily enter areas of erosion or deposition. In the Rock River Valley, forests were found on slopes and bottomlands. The uplands were originally prairie.

The prairie is favored by fire (usually introduced by man) which injures the aerial parts of woody plants while the underground vegetative structures of prairie grasses and forbs survive. Prevailing winds drive fires eastward with the result that the pioneers found much more extensive forests to the east of rivers than on the western side. Actual presence or occupancy of the ground favors prairie. The heavy sod is not easily penetrated by seedlings. Also, the prairie uses all of the available surface moisture. The prairie needs sun, however, so it is inhibited at the edges of forests by shade, and the forest moves slowly into an adjacent prairie. If the ecotone contains species that spread vegetatively, such as species of *Populus* and *Rhus*, they gradually extend into the prairie and destroy it through shading.

In the study area, we see these factors at work. The most rapid tree development has occurred in gullies, where the soil and rock have been exposed. Along the forest edges, the species of the forest, especially oaks and walnuts, are developing rapidly. In the open pasture, the pioneer trees are much less abundant and are almost entirely those species with seeds easily carried by the wind or those ingested and later deposited by birds.

In the Strong Field introduced domestic plants and weeds first penetrated the bluegrass sod. Many were probably present in the bluegrass pasture during the period of grazing. Gradually these were replaced by native species of prairies and open areas. The herbaceous flora typical of forests have entered slowly after the trees became established.

Clones of shrubs and small trees, especially sumac, aspens, and blackberry, have served as protection for seedlings of trees such as walnut. The presence of shrubs and trees speeds the development of forest and the disappearance of prairie plants.

Native prairie grasses have had little development in the Strong Field. Tall grama-grass on a gravelly hillside has been eliminated by sumac. A few bunches of Indian grass have slowly enlarged and multiplied over the past decade but nearby aspens have been entering the area and will eventually destroy the grass unless man intervenes.

It is becoming obvious that the Strong Field is destined to become forest in the course of natural secondary succession. In twenty years the open bluegrass pasture has been effectively penetrated by both woody and herbaceous species, but the trees and shrubs are rapidly assuming dominance.

In this situation, small prairie openings can be maintained only by considerable effort. The limited available evidence indicates that there is a possibility of doing this by the use of chemical spraying and by pulling or grubbing out invaders. Future efforts will be made to accomplish this.

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Appendix I
TREES OF STRONG FIELD

Acer negundo L.	box-elder
Betula papyrifera Marsh.	white birch
Carya ovata K. Koch	shagbark-hickory
Celtis occidentalis L.	hackberry
Cratægus crus-galli L.	cockspur-thorn
Cratægus mollis Scheele	red haw
Fraxinus americana L.	white ash
Gleditsia triacanthos L.	honey loccust
Juglans nigra L.	black walnut
Juniperus virginiana L.	red cedar
Populus deltoides Marsh.	cottonwood
Populus grandidentata Michx.	large-toothed aspen
Populus tremuloides Michx.	quaking aspen
Prunus americana Marsh.	wild plum
Prunus serotina Ehrh.	black cherry
Ptelea trifoliata L.	wafer-ash
Pyrus iœnsis Bailey	wild crab
Pyrus malus L.	apple
Quercus alba L.	white oak
Quercus macrocarpa Michx.	burr oak
Quercus rubra L.	red oak
Quercus velutina Lam.	black oak
Tilia americana L.	basswood
Ulmus americana L.	American elm
Ulmus rubra Muhl.	red elm
Ulmus pumila L.	Siberian elm

Appendix II
SHRUBS AND VINES OF STRONG FIELD

Cornus racemosa Lam.	gray dogwood
Parthenocissus quinquefolia Planch.	Virginia creeper
Rhus glabra L.	smooth sumac
Rhus radicans L.	poison ivy
Ribes missouriense Nutt.	Missouri gooseberry
Rosa arkansana Porter var. *suffulta* Cockerell	prairie rose
Rosa multiflora Thunb.	multiflora rose
Rubus allegheniensis Porter	blackberry
Rubus flagellaris Willd.	creeping blackberry
Rubus occidentalis L.	black raspberry
Sambucus canadensis L.	common elderberry
Vitis Labrusca L.	fox-grape

Appendix III
HERBACEOUS PLANTS OF STRONG FIELD
(Naturalized or Introduced)

Abutilon theophrasti Medic.	velvet-leaf
Achillea millefolium L.	common yarrow
Cirsium arvense Scop.	Canada thistle
Cirsium vulgare Tenore	common or bull thistle
Convolvulus arvensis L.	field-bindweed
Dianthus armeria L.	Deptford pink
Medicago lupulina L.	black medick
Melilotus alba Desr.	white sweet clover
Melilotus officinalis Lam.	yellow sweet clover
Phleum pratense L.	timothy
Plantago major L.	common plantain
Poa pratensis L.	Kentucky bluegrass
Portulaca oleracea L.	common purslane
Rumex acetosella L.	sheep sorrel
Rumex crispus L.	yellow dock
Setaria glauca Beauv.	foxtail
Taraxacum officinale Weber	common dandelion
Tragopogon pratensis L.	goat's-beard
Trifolium pratense L.	red clover
Trifolium repens L.	white clover
Verbascum thapsus L.	common mullein

Appendix IV
HERBACEOUS PLANTS OF STRONG FIELD
(Native Plants of Prairies, Meadows, Clearings, or Waste Places)

Ambrosia artemisiifolia L.	common ragweed
Ambrosia trifida L.	great ragweed
Amorpha canescens Pursh	leadplant
Andropogon scoparius Michx.	little blue-stem grass
Anemone cylindrica Gray	thimbleweed
Antennaria neglecta Greene	pussy's toes
Asclepias sullivantii Engelm.	milkweed
Asclepias verticillata L.	whorled mildweed
Aster lævis L.	white aster
Aster novæ-angliæ L.	New England aster
Bouteloua curtipendula Michx.	tall grama-grass
Campanula americana L.	tall bellflower
Carex sp.	sedge
Desmodium illinœnse Gray	tick-trefoil
Erigeron annuus Pers.	daisy fleabane
Euphorbia corollata L.	flowering spurge
Helianthus sp.	sunflower
Hypericum perforatum L.	St. John's-wort
Lactuca ludoviciana Riddell	wild lettuce
Monarda fistulosa L.	wild bergamot
Oxalis stricta L.	yellow wood-sorrel
Panicum L. sp.	panic-grass
Petalostemum purpureum (Vent.) Rydb.	prairie-clover
Physalis virginiana Mill.	ground-cherry
Potentilla arguta Pursh	tall cinquefoil
Prunella vulgaris L.	heal-all
Rudbeckia hirta L.	black-eyed Susan
Rumex altissimus Wood	pale dock
Solanum carolinense L.	horse-nettle
Solidago sp.	goldenrod
Sorghastrum nutans Nash	Indian grass
Tradescantia ohiensis Raf.	spiderwort
Verbena stricta Vent.	hoary vervain

Appendix V
HERBACEOUS PLANTS OF STRONG FIELD
(Native Plants Commonly Found in Forests or Wooded Areas)

Amphicarpa bracteata Fern.	hog-peanut
Apocynum androsæmifolium L.	spreading dogbane
Aquilegia canadensis L.	wild columbine
Eupatorium rugosum Houtt.	white snakeroot
Galium circæzans Michx.	wild licorice
Liparis lilifolia Richard	broad-leaved twayblade
Lobelia siphilitica L.	great blue lobelia
Orchis spectabilis L.	showy orchis
Physalis heterophylla Nees	ground cherry
Sanicula gregaria Bickn.	black snakeroot
Teucrium canadense L. var. *virginicum* Eat.	wood-sage
Verbena urticifolia L.	white vervain

The Role of Allelopathy in Old-Field Succession on Grassland Areas of Central Oklahoma

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Studies in allelopathy, or the detrimental effect that one plant has upon another through the production of toxic compounds, have been going on at the University of Oklahoma since 1963. E. L. Rice initiated these studies in answer to the anomalies that exist in the succession story that occurs on the abandoned fields of central Oklahoma. Since that time Rice and his collaborators have utilized the phenomenon of allelopathy to present a more realistic explanation for the natural revegetation of abandoned fields in the grasslands of this region.

Booth (1941) depicted succession in abandoned fields of central Oklahoma and southeastern Kansas as proceeding through four major stages: (1) weed stage, lasting 2–3 years, composed of *Helianthus annuus, Erigeron canadensis, Digitaria sanguinalis, Haplopappus ciliatus, Croton glandulosus* and others; (2) annual grass for 9 to 13 years, dominated by *Aristida oligantha*; (3) perennial bunchgrass, lasting an undetermined length of time dominated by *Andropogon scoparius*, and (4) the climax prairie dominated by *A. scoparius, A. gerardi, Panicum virgatum* and *Sorghastrum nutans.*

The usual generalized explanation for the successional changes is that each stage increases the supply of minerals and organic matter, and improves soil structure and water relationships thus creating an environment that is more conducive to the incoming than the outgoing species. Such a generalized story, however, cannot explain why the first stage is replaced so rapidly by *A. oligantha*, because we have obtained considerable evidence indicating that *A. oligantha* thrives under lower conditions of fertility and water supply than required to support most of the species in the pioneer weed stage.

The second puzzling point here, is the very slow invasion of abandoned fields by climax grasses, even when such species completely surround the fields. Rice, Penfound and Rohrbaugh (1960) established that ecsesis rather than seed dispersal is the problem involved in the invasion of the climax grasses.

Observations made on fields having varying lengths of abandonment substantiated the findings of Smith (1940), who stated that the first plant of the weed stage to be lost is *Digitaria*, followed by *Helianthus* and *Haplopappus*. The last three species become stunted and fewer in number each succeeding year. Field inspection and sampling around *Helianthus annuus*, one of the most prominent and important species in the first stage, indicated that certain species of plants do not grow well close to *H. annuus* plants while others appear even to be favored (Table 1).

Soil taken from around sunflower plants at 0.25 m and 1 m were compared for certain selected mineral and physical properties, i.e. soil reaction, organic carbon, total nitrogen and total phosphorus. The differences in the soils from these two areas did not appear enough to be responsible for the vegetative patterns that developed around the sunflowers.

Since competition, or the reduction of some factor in the environment that is required by some other plant sharing the habitat, apparently could not explain the zones of inhibition surrounding the sunflower plants some other phenomenon must be at play in these old-fields. Recent review articles by Muller (1966) and Rice (1967) pointed out numerous studies which indicate that allelopathy may play an important role in the structure and composition of plant communities. Certainly, the zones surrounding *H. annuus* suggested the presence of phytotoxic compounds. With this in mind a study was undertaken to ascertain what role *H. annuus* may play in aiding the self-elimination of the weed stage and its passage into the annual grass stage.

Extract tests indicated that certain phenolic compounds, i.e. isochlorogenic and chlorogenic acids, isolated from sunflower plants by paper chromatography were toxic to seed germination and seedling growth of itself and many of its associated species. To be ecologically active, however, these phytotoxins must leave the sunflower and enter the environment. It was postulated that the phytotoxic materials may escape *H. annuus* by at least three methods: decomposition of sunflower debris, exudation by roots, and leaching from leaves.

One gram of air dried sunflower leaf, equivalent to that produced per 454 g of soil in the top 17 cm of a stand of sunflowers, was added to pots containing seeds of *H. annuus* or associated species. Controls were run with 1 g of air dried peat moss. The decaying material of *H. annuus* affected the growth of all associated species except *A. oligantha* (Table 2). The active phytotoxin that escapes from decaying sunflower leaves appears to be scopoletin.

TABLE 1

Results of field clippings of species associated with Helianthus annuus.

Species	Number of sunflowers sampled	Mean oven-dry weight in g/0.25 m² — Quadrats[a] A	B	C	Fs
Erigeron canadensis	100	7.64	10.78	26.97	21.8[b]
Rudbeckia hirta	100	0.23	0.51	0.63	12.5[b]
Haplopappus ciliatus	100	5.38	8.06	11.88	1.7
Bromus japonicus	75	1.74	2.96	4.52	2.8
Croton glandulosus	100	5.50	9.27	2.22	2.9

[a]Quadrat A includes the sunflower plant.
Quadrat B extends 0.5 m from quadrat A.
Quadrat C extends 0.5 m from quadrat B.

[b]Significant difference among quadrats.

Data of Roger E. Wilson, previously unpublished.

TABLE 2

Effects of decaying sunflower leaves on growth of seedlings and germination.

Test Species	Expt No.	Mean dry weight of seedlings, mg — Control	Test	Fs	Germination[b]
Helianthus annuus	1	44	22[a]	45.4	52
	2	36	21[a]	10.7	40
Erigeron canadensis	1	54	19[a]	20.0	87
	2	32	16[a]	9.4	71
Rudbeckia hirta	1	17	3[a]	36.0	95
	2	12	2[a]	19.3	81
Digitaria sanguinalis	1	126	16[a]	67.8	106
	2	97	11[a]	84.4	97
Amaranthus retroflexus	1	78	12[a]	23.7	56
	2	91	16[a]	41.6	32
Haplopappus ciliatus	1	13	8[a]	7.0	71
	2	26	10[a]	12.6	64
Bromus japonicus	1	47	17[a]	114.0	97
	2	39	15[a]	71.8	94
Aristida oligantha	1	15	21	3.7	97
	2	19	23	2.2	102

[a]Dry weight significantly different from control.

[b]Expressed as percent of the control.

Data of Roger E. Wilson, previously unpublished.

Leaf leachate from *H. annuus* was produced by spraying artificial rain over the plants. The leachate was tested against the growth of the species as listed in Table 2. The leachate containing two phytotoxins, an α-napthol derivative and scopolin, was found to be inhibitory to the growth of all species tested except *Helianthus* itself, *C. glandulosus*, *B. japonicus* and *A. oligantha*.

The growth of the same group of seedlings was tested for their behavior with sunflower root exudate. This was done by continuously pumping culture solution through a series of alternating pots of sunflower plants and test seedlings (test series) or through a series of pots of test seedlings only (control series). All species were significantly inhibited in growth except *H. ciliatus*, *B. japonicus*, *C. glandulosus* and *A. oligantha*. The phytotoxic agents in the root exudate of sunflower plants have not been characterized.

The same set of test species (Table 2) were also grown in soils collected within 0.25 m of sunflower plants and compared with the growth of those grown in soils collected at a distance greater than 1 m from sunflower plants. There was a significant reduction in the growth of all species except *H. ciliatus*, *B. japonicus*, *C. glandulosus* and *A. oligantha*.

Thus it appears that those species inhibited in the field were also inhibited by the laboratory tests. *A. oligantha*, however, the chief dominant in Stage 2 of old-field succession, was not inhibited by any test.

Parenti (1968), working with *Digitaria sanguinalis*, and Abdul-Wahab and Rice (1967) with *Sorghum halepense* have demonstrated that these two important species of Stage 1 also exert allelopathic effects against species of Stage 1 but do not inhibit *A. oligantha*. It appears, therefore, that inhibitors produced by species of stage 1 may eliminate the species of that stage rapidly. *A. oligantha* possibly invades next because it is not inhibited by the toxins produced by species of Stage 1 and is able to grow in the infertile soil.

A partial explanation for the long duration of the depauperate *A. oligantha* may also lie in the realm of allelopathy. These abandoned fields are generally low in nitrogen and phosphorus. Rice, Rohrbaugh and Penfound (1960) studied the nitrogen and phosphorus requirements of three species which come into the revegetating old fields at different stages. They found the apparent order of the three species based on increasing requirements for nitrogen and phosphorus to be as follows: triple awn grass, little bluestem and switchgrass. This order is also the relative order in which these three species invade abandoned fields. Therefore any factors which would regulate the rate of formulation or accumulation of available nitrogen or rate of accumulation of phosphorus in these areas would affect the rate of succession.

Rice hypothesized that the low nitrogen requiring early plant invaders of abandoned fields may produce inhibitors of the nitrogen-fixing and nitrifying bacteria. This would give such plants a selective advantage over plants with higher nitrogen requirements, and could conceivably slow down plant succession.

TABLE 3

Effects of root exudates of inhibitor species on nodulation of legumes.

Inhibitor Species	Average Nodule Number With Standard Error					
	Red Kidney Bean		Korean Lespedeza		White Clover	
	Control	Test	Control	Test	Control	Test
FORBS						
Ambrosia psilostachya	180.6±10.0	62.1± 3.8[a]	8.1±0.3	3.9±0.2[a]	8.2±0.6	4.3±0.4[a]
Euphorbia supina	198.4±11.2	181.4±16.4	14.0±0.5	6.5±0.5[a]	5.5±0.3	4.2±0.4[a]
Helianthus annuus	298.6±17.4	22.5±2.8[a]	17.0±1.5	2.3±0.6[a]	6.5±0.6	0.4±0.1[a]
GRASSES						
Aristida oligantha	214.3±12.3	145.5±7.7[a]	6.4±0.2	5.5±0.3[b]	11.1±0.7	4.3±0.4[a]
Bromus japonicus	129.8± 5.1	127.7±5.5	9.9±0.3	6.5±0.3[a]	5.9±0.8	2.3±0.4[a]
Digitaria sanguinalis	174.1± 7.7	109.2±6.3[a]	14.1±0.6	8.3±0.5[a]	19.5±1.0	3.5±0.4[a]

a/ Difference from corresponding control significant at better than the 0.001 level.

b/ Difference from corresponding control significant at the 0.01 level.

Data of E. L. Rice, previously unpublished.

In extract studies Rice found twenty-four species of plants which are of some importance in revegetating old-fields as having inhibitory activity against Azotobacter, Rhizobium, Nitrobacter and Nitrosomonas.

Using a setup similar to that previously described for sunflowers Rice found that root exudates of six selected inhibitor species significantly reduced the nodule numbers of most test legumes (Table 3). In addition to reducing the nodule numbers on inoculated legumes, the inhibitor species caused the nodules to be smaller and gray in color rather than large and pink as on the controls. Quantitative analyses of the hæmoglobin content of the nodules demonstrated that there was less hæmoglobin in test nodules than controls. Clearly then, the N-fixing ability of the legumes associated with the inhibitor species was less than that of the controls.

Another source of nitrogen formulation and accumulation, the blue-green algæ, has been investigated in these old-fields by Parks (1968). He found the root exudates, leaf leachates and known inhibitors isolated from many of the pioneer weeds to be inhibitory to the growth of many of the blue-green algæ naturally occurring in these fields.

Blum (1968) has found that gallotannic and gallic acids found in the soils beneath *Euphorbia supina* and *Rhus copallina* are quite inhibitory to the nitrogen-fixing and nitrifying bacteria.

These studies indicate that species from Stage 1 may eliminate that stage rapidly allowing *A. oligantha* to invade next because it is not inhibited by the toxins produced by the species of Stage 1 and is able to grow in the infertile soils. The low nitrogen content of these soils may then be maintained by the toxic compounds of *A. oligantha* and the residual toxins of Stage 1 which are inhibitory to the nitrogen-fixing and nitrifying organisms. Thus it appears that allelopathy may play a major role in the sequence and timing of the revegetation on old-fields in central Oklahoma.

Allelopathy, however, is one of the many plant-plant, plant-animal interactions one must consider in attempting to establish artificial prairie plots. I fear that proper consideration has not been given to these factors in the establishment of artificial grasslands; as evidenced by the high failure ratio of numerous attempts. It is hoped that the future will have more than mere artificial grasslands for memories. And so may I call here for more basic research in grasslands ecology, a greater adherence to the findings of grassland ecologists, and to the preservation of natural grasslands that still exist.

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Session on: SOILS AND FERTILITY

Session Moderator: **DAVID ARCHBALD**

Managing Director of the Arboretum and Wildlife Refuge, University of Wisconsin, Madison

Fertility Level of a Hay-Cropped Prairie*

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In June, 1968, the Minnesota Chapter of The Nature Conservancy made final payment on a 160 acre tract in McLeod County, Minnesota (SE¼ of Section 34, Township 29 West, Range 115 North). Title was thus acquired to one of the finest remaining examples of tall grass prairie once so prevalent in this state. An important function of The Nature Conservancy is to locate, acquire and preserve areas such as the Schaefer Prairie that they may serve as scientific reference points of relatively primeval conditions.

The Schaefer Prairie, so named for the family that originally acquired the property in 1881, has been preserved due to the interest in and love of the prairie by Mrs. Warren Leonard, a daughter of the Schaefer family. Reluctantly she had permitted breaking of 40 acres to meet taxes and other expenses. Her constant wish throughout the years had been that the remaining prairie be kept unbroken.

The Schaefer Prairie, as presently constituted, embraces approximately 90 acres of prairie vegetation including two potholes, 40 acres of the above mentioned plowland (hatched area in Figure 1) and 30 acres of bottom land which is occupied in part by Buffalo Creek. The prairie area is thought to

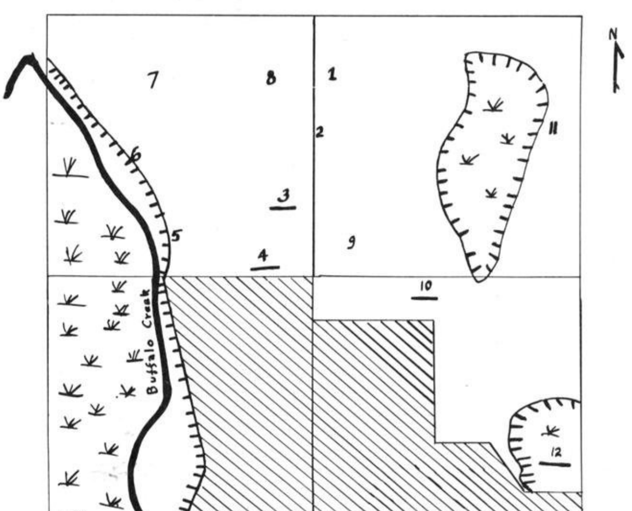

FIGURE 1

The Schaefer Prairie showing the approximately 90 acres in prairie vegetation (white area), 40 acres of cultivated land (hatched area) and 30 acres of marshy land and creek bottom. Numbers 1 through 12 indicate points where soil samples were taken. Underlined collection points had a pH above 7.0.

be typical of the tall grass prairie that occupied much of central and western Minnesota prior to European settlement. The dominant grasses on the better drained sites are big bluestem (*Andropogon gerardi* Vitman), little bluestem (*A. scoparius* Michx.), Indian-grass [*Sorghastrum nutans* (L.) Nash], porcupine-grass (*Stipa spartea* Trin.) and side-oats grama [*Bouteloua curtipendula* (Michx.) Torr.]. Prairie cordgrass (*Spartina pectinata* Link) is the predominant grass of poorly drained sites. Introduced grasses such as smooth bromegrass (*Bromus inermis* Leyss.), timothy (*Phleum pratense* L.) and Kentucky bluegrass (*Poa pratensis* L.) are relatively important invaders in some parts of the prairie. Reed canarygrass (*Phalaris arundinacea* L.) is the common grass of the creek bottom land.

The only sustained use of the land, other than the breaking of the 40 acres, has been annual hay-cropping. In recent years, however, the market for native hay has largely disappeared and cutting has been irregular. Occasionally the uncut hay has been burned. Prairie hay was cut late in the season to avoid porcupine-grass awns, the presence of which could cause serious trouble if they lodged in the mouths or throats of livestock. While probably never highly nutritious prairie hay did provide enough sustenence to carry stock through the winter.

In august 1968, while visiting the Schaefer Prairie, Dr. Lawrence Foote of the Minnesota Highway Department commented upon the apparently impoverished appearance of many of the plants, especially the prairie grasses. Heavy invasion by sweet clover (*Melilotus alba* Desr.) and black medic (*Medicago lupulina* L.), both indicative of low fertility, and red clover (*Trifolium pratense* L.) was noted. Sweet clover was particularly abundant near the bordering town roads on the north and east. Seed stalk production and flowering were noticeably scant and the panicles small on the prairie grasses. By contrast forbs, notably the composites, appeared relatively vigorous.

As an explanation for the low vigor of the grasses it seemed reasonable to assume a depletion of fertility due to the annual removal from the site of many tons of hay with a consequent interruption of the normal recycling of nutrients. Under presettlement conditions the nutrients largely remained on the site. Grazing animals such as bison, elk and deer moved about considerably but in the long run left as much material as that consumed, so that little or no depletion occurred. On the other hand, hay such as timothy, is reported to contain about 25 pounds of nitrogen, 4.8 pounds of elemental phosphorus reported as P_2O_5 and 16.6 pounds of potassium reported as K_2O (Millar *et al.*, 1958) per ton. If prairie grasses have similar nutrient requirements the drain on the soil from long continued hay-cropping is evident.

The soils of the Schaefer Prairie belong to the Lakeville-Clarion series ranging from Lakeville sandy loam through Clarion silty loam with some Nicollet, Webster and Glencoe clay loams. The Webster and Glencoe silty clay loams are mostly confined to the low areas of relatively poor drainage around the potholes. These soils all developed under a cover of native prairie grasses and may range to a depth of 20 inches of dark granular surface soil.

To determine the present condition of the Schaefer Prairie soils, samplings were made to a depth of about 5 inches at 12 selected representative sites (Fig. 1) and submitted to the University of Minnesota soil testing laboratory. From the results of the tests (Table 1) it is evident that for normal agricultural purposes the N-P-K nutrient level is extremely low.

TABLE 1

Results of soil tests of 12 selected sampling points on the Schaefer Prairie with nutrients indicated in pounds per acre.

	Sample number												Suggested levels for crop land
	1	2	3	4	5	6	7	8	9	10	11	12	
pH	6.3	6.5	7.1	7.7	6.1	6.3	6.2	6.5	6.1	7.5	6.3	7.8	
N	14	14	10	14	20	20	14	14	14	14	20	14	40-80
P @	1	1	1	1	1	1	1	1	1	1	1	1	10-30
K	4	6	4	16	4	4	4	4	4	4	4	4	75-170
Ca	92	128	184	308	118	106	110	118	106	440	132	366	

*Misc. Report, Experiment Station, Dept. of Horticultural Science, University of Minnesota.

How important these nutrient deficiencies are under prairie conditions is difficult to assess. Any opinion must necessarily be somewhat speculative since a truly unexploited prairie has not been located in the area. However in an old report (Snyder, 1914) of the chemical composition of virgin Minnesota prairie soils the major nutrients reported as N, P_2O_5 and K_2O were present in the amounts of 0.38%, 0.35% and 0.45% respectively. These levels are many times those now present in the Schaefer Prairie soils and it seems reasonable to infer that long continued hay-cropping has contributed to the decline in fertility.

Calcium levels, unlike N-P-K, are ample in all but sample 1 and are indeed excessive in samples 3, 4, 10 and 12 where the pH is above 7.0. Samples 3 and 4 were taken from gravelly ridges containing an excess of limestone, while samples 10 and 12 were obtained near the potholes where evaporation has caused an accumulation of carbonates.

Since it is contrary to the policy of The Nature Conservancy to hold land for income purposes it is planned to return the 40 acres of cultivated land to prairie vegetation as quickly as an orderly procedure can be implemented. At present the program calls for the annual withdrawal of about 10 acres followed by overseeding of the stubble land with seed collected from the adjoining prairie. Only local seed from the Schaefer Prairie is to be used in the restoration since little factual information is available on the significance of ecotype development in Minnesota prairie species.

The amount of seed required to be collected to reseed 40 acres is considerable. Under good conditions at least ten pounds of pure live seed per acre of the warm season prairie grasses will be needed to obtain stands that may compete successfully with common ruderals and agricultural weeds of the area. If seed production is poor on the prairie grasses it may prove difficult to supply the needs of the planting program.

As stated above the seed panicles of the major grass species appeared small and the total height of the taller species such as Indian-grass and big bluestem rarely exceeded four feet. This is small stature indeed compared to early descriptions of the prairie in pioneer Minnesota where one may read, "Here are also splendid meadows, where the grass grows higher than a man's head," or, "There is such an amount of vegetation in the woods that fire will run there, as well as in the meadow where the grass is 14 feet high (for there was grass in Mr. Lyman's meadow as high as that)" (Nichols, 1939). In further striking contrast to the present unproductive condition of the Schaefer Prairie is the surrounding developed cropland which is among the most highly productive in Minnesota.

Some seed was collected in 1968 from the common prairie grasses on the Schaefer Prairie for the purpose of establishing a seed production nursery on some of the cultivated land. Seed was obtained from porcupine-grass, big and little bluestem, side-oats grama, Indian-grass, switchgrass (*Panicum virgatum* L.). Canada wildrye (*Elymus canadensis* L.) and Virginia wildrye (*E. virginicus* L.).

Since it proved relatively easy to clean and to determine by actual count the percentage of good seed, *i.e.*, spikelets, containing sound caryopses, Indian-grass was chosen for seed analysis. Percentages of filled spikelets were determined from mass collected "seed" from the Schaefer Prairie and for comparison from six other stands of Indian-grass in southern and central Minnesota. No determination of the number of spikelets produced per panicle was made. The weight per thousand seeds (caryopses) was determined as a possible index of seed quality. For this latter analysis an additional collection from Burnsville, Scott County, was included.

Table 2 indicates that seed production on the Schaefer Prairie, calculated on the percentage of filled spikelets, was well below the standard deviation from the mean of the seven areas sampled, thereby giving support to the hypothesis of soil impoverishment and consequent low seed production. On the other hand the caryopses produced by Indian-grass on the Schaefer Prairie were heavier than all other samples except the Burnsville source. Thus while the quantity of filled seed produced is low the apparent quality is good.

On the basis of these observations on Indian-grass it appears that good prairie grass seed production on the Schaefer Prairie might be achieved most readily by cultivation of some basic stock in nursery rows. Fertilization of existing stands to improve their productivity has been proposed. This recourse has been logically opposed on the basis that it is not advisable to resort to such manipulation on an area set aside as a scientific preserve. It seems quite proper on the other hand to incorporate some small fertilization research in order to ascertain the importance of fertility levels to prairie grass populations, seed production and seedling establishment.

Whether or not these preliminary observations on Indian-grass, which do not take into consideration the possible genetic variations between sources, can be extrapolated to the other warm season prairie grasses has not been determined. In four samples of side-oats grama (Table 3) seed (caryopses) collected from the Schaefer Prairie was smaller than the mean in excess of the standard deviation while seed collected from cultivated plants in the University of Minnesota Landscape Arboretum was larger beyond the standard deviation.

TABLE 2

Seed production by Indian-grass [Sorghastrum nutans (L.) Nash] from eight Minnesota sources.

Source	Number of spikelets sampled	Filled spikelets	Empty spikelets	Percentage Filled	Weight per 1000 caryopses
Schaefer Prairie, McLeod County	1223	164	1059	13.40	1.644 gm.
Eden Prairie Township, Hennepin County	2073	778	1295	37.55	1.442 gm.
Carver Creek, Carver County	1207	704	503	58.33	1.588 gm.
St. Paul, Ramsey County	1528	382	1146	25.00	1.284 gm.
North Carver, Carver County	1439	435	1004	30.23	1.336 gm.
Brainerd, Crow Wing County	1273	332	941	26.08	1.420 gm.
Allison Savanna, Anoka County	1673	644	1029	38.49	1.176 gm.
Burnsville, Scott County	----	---	----	-----	1.784 gm.
	10416	3439	6977	$\bar{X}$ = 33.02 s = 14.120	$\bar{X}$ = 1.459 s = 0.2155

TABLE 3

Relative size of caryopses of side-oats grama [Bouteloua curtipendula (Michx.) Torr.] from four sources as indicated by 1000 seed weight.

Source	Weight per 1000 caryopses
Schaefer Prairie, McLeod County	0.484
Eden Prairie Township, Hennepin County	0.560
San Francisco Township, Carver County	0.582
University of Minnesota Landscape Arboretum, Carver County (Cultivated)	0.676
	$\bar{X}$= 0.575 s= .07907

During the next few years of planned restoration of prairie on the 40 acres of cropland on the Schaefer Prairie property we anticipate the accumulation of considerable data relating to the interactions of soil fertility, prairie species seed production and seedling establishment.

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Soil Genesis Under Prairie

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It is useful to review our knowledge of processes of formation of soils under prairies, particularly in view of the fact that the Chernozem (Boroll)[1] soil was the principal subject of the study of V. V. Dokuchaev in the course of which he established the concept of soil as a definite natural body with genetic layers called horizons (Dokuchaev, 1899). This paper is written with emphasis on observations in the prairie-forest tension zone in southwestern Wisconsin, where the soils are more leached than in the Chernozem zone. Thorp (1948), Aandahl et al. (1960), and Riecken (1965) have presented more comprehensive discussions of pedogenic processes of soils of temperate regions, including soils of prairies and former prairies.

Use of quantitative data in the precise definition of soil categories (Soil Survey Staff, 1951, 1960) has enlarged our model of soil (Cline, 1961) beyond the early Russian idea of climatic zonality of soils (Baldwin et al., 1938) and beyond a Davisian—Marbutian concept of "normal" soil (Marbut, 1951) in "climax" equilibrium with the environment. We find among students of soils an increasing appreciation of the roles of geomorphology, time, and organisms in ever progressive soil development.

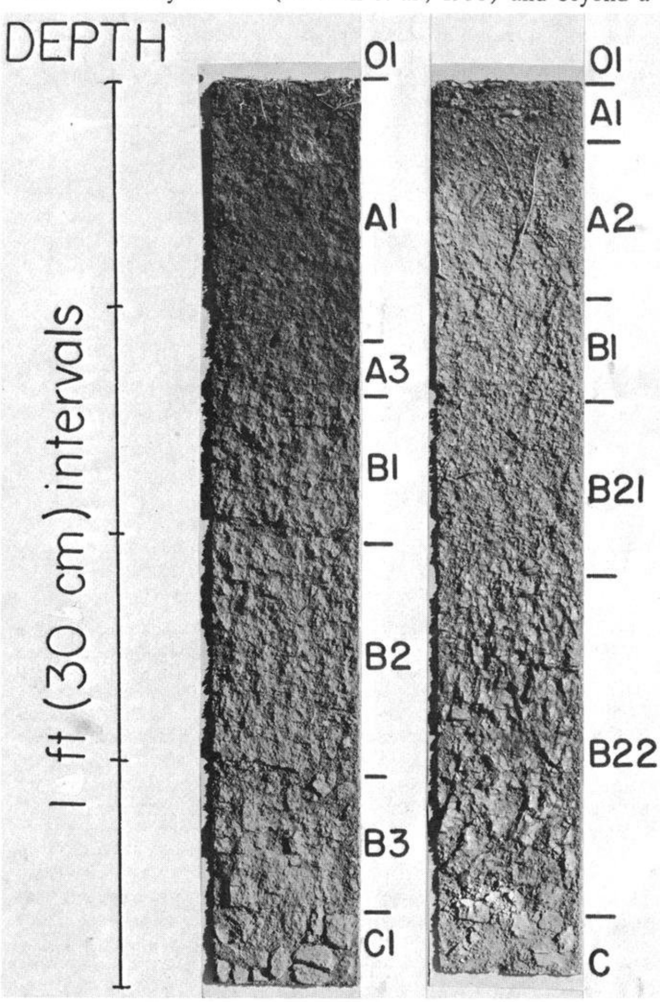

FIGURE 1

Soil profile of the Tama silt loan (left), a Brunizem soil; in contrast with the soil profile of a Fayette silt loam (right), a Gray-Brown Podzolic soil.

Marbut (1951) suggested that geologists have more opportunity to observe geological processes both in miniature and on a large scale than pedologists have to witness the formation of a mature soil. Jenny (1941) wrote that "our ideas about soil genesis as revealed by profile criteria are inferences . . . theories, not facts." Since these words were written soil scientists and ecologists have made many observations of processes of soil formation and have accumulated data about them, with corresponding modification and elaboration of theory. Emphasis has shifted from an almost exclusive consideration of factors of soil formation (Jenny, 1941, 1958) to an analysis of processes of soil formation (Simonson, 1959).

Combinations of processes of soil genesis under prairie cover are best considered in contrast with combinations of processes, many of them the same ones, under associated forests. Figure 1 shows side by side a prairie soil (Brunizem[2], Hapludoll) and a deciduous forest soil (Gray-Brown Podzolic, Hapludalf). The differences between them have been traditionally ascribed to differences in assemblages of organisms on them, all other factors (initial material, topography, macroclimate and age) having been presumed to be the same. Quantitative data on the differences in soil formation between prairie and forest ecosystems are accumulating.

GENERAL KINDS OF PEDOGENETIC PROCESSES

Two kinds of pedogenetic processes may be distinguished (Hole, 1961) on the basis of degree of complexity of soil profile: (1) those processes which produce a multiplicity of soil horizons in a soil profile; and (2) those processes which simplify the horizonation of soil profiles by inhibiting multiplication of horizons or by homogenizing two or more horizons into one. A product of the first group of processes is the "double profile" called a bisequum. The bisequal soil in figure 2 (postulated soil profile at 10,000 years before present) has five major soil horizons above the C horizon, including two

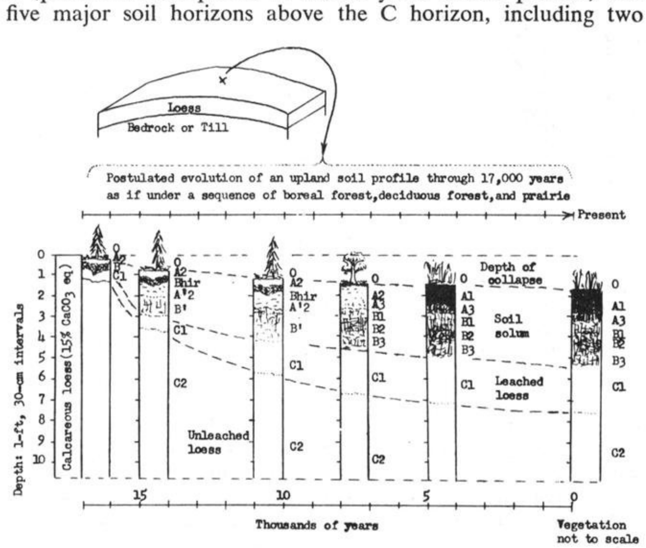

FIGURE 2

A-B sequences. A product of the second group of processes is the calcareous A1-C soil profile of the Grumusols (Vertisols) of the black cotton belt of Mississippi (Oakes and Thorp, 1951). Differential translocation and accumulation of materials result-

[1]The term Boroll and similar terms in this paper are from the new soil classification of the U.S.D.A. (Soil Survey Staff, 1960, 1967).

[2]This term was proposed in Iowa (Simonson, et al, 1952) and is now commonly used to avoid the former practice of using the plant community term, "prairie," in reference to the soil. S. A. Wilde (pers. communication, 1968) deplores the term Brunizem from the standpoint of semantics and prefers Brunisol or Bruniterra.

ed in the first profile. A mixing ("self-plowing"; pedoturbation) by shrink-swell of highly expansible clay produced the second profile. The two categories of processes are not mutually exclusive, because soil mixing of O (organic) and A2 (leached surface soil) is important in the genesis of the thin nearly black A1 horizon of many forest soils (figure 3). Under prairie and

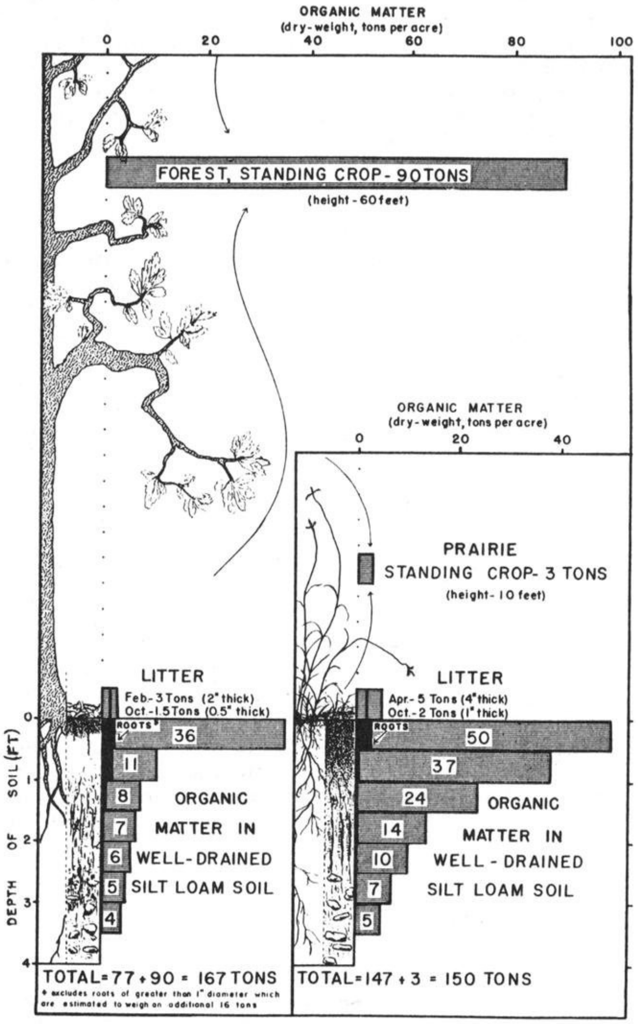

FIGURE 3

The distribution of organic matter in forest (white oak, Quercus alba; **black oak,** Q. velutina) **and prairie (big bluestem,** Andropogon gerardi; **Indiangrass,** Sorghastrum nutans) **ecosystems in south central Wisconsin; generalized presentation. (Nielsen and Hole, 1963.)**

in former prairie areas we find soils with A1-C profiles (prairie soils, Brunizems: Entic Hapludoll; Entic Haplustoll), others with A1-B-C (Brunizems: Typic Hapludoll as in figure 4; Typic Argiudolls, Typic Argiustolls) and A1-A2-B-C profiles (Planosols: Typic Argialbolls), and at poorly drained sites, A1-Bg-Cg profiles (Humic Gley soils: Typic Haplaquolls and Argiaquolls). In the first profile either youth or sandy texture of initial material or biotic mixing (faunal pedoturbation) accounts for the development of a soil profile with few horizons. Where downward translocation of mineral colloids and/or influence of high water table have predominated over pedoturbation, soil profiles with several contrasting horizons have formed. It is estimated that an A1 horizon in a prairie soil can form in 500 years, and a textural B horizon in 4,000 years (Arnold and Riecken, 1964). A prairie soil (mollic) A1 is slowly being reformed in the University of Wisconsin Arboretum under prairie vegetation planted in 1940 (figure 5).

Wilde (1958) has contrasted melanization, the processes that accumulate dark humus in dominantly mineral soil horizons, with leucinization, those processes which destroy and remove dark humus, leaving mineral grains uncoated so that

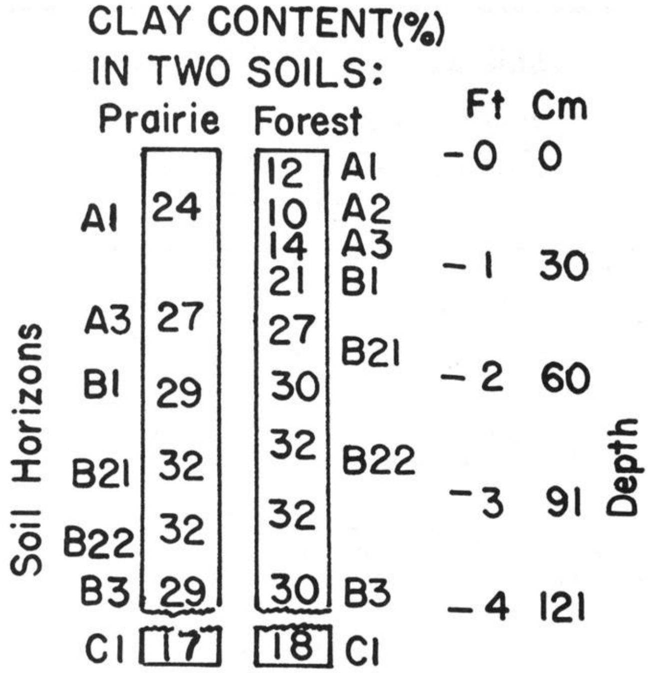

FIGURE 4

Percent clay on a dry weight basis in horizons of a prairie soil (Tama silt loam, Typic Hapludoll) and adjacent forest soil (Fayette silt loam, Typic Hapludalf) in southwestern Wisconsin (data from Fanning and Jackson, 1965).

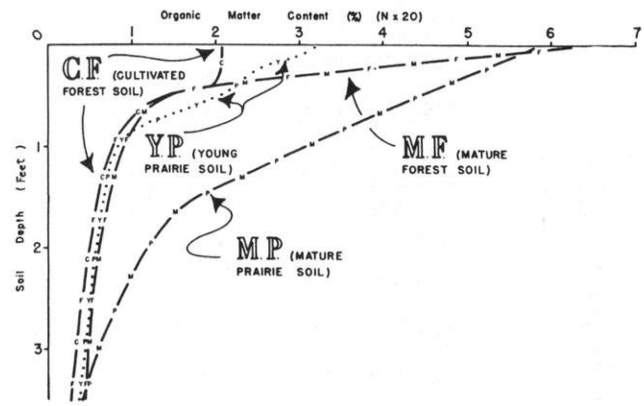

FIGURE 5

Distribution of organic matter in a mature soil under forest (Noe Woods, University of Wisconsin Arboretum), a forest soil cropped for about 90 years (Curtis prairie, U. W. Arboretum), a cropped forest soil under prairie vegetation for 19 years (portion of the Curtis prairie planted in 1940) and a mature prairie soil (generalized data from Shields, 1955; Simonson, et al, 1952; Nielsen and Hole, 1963).

they impart a light color to the horizon. Melanization has produced dark A horizons and dark coatings on ped surfaces in the B and C horizons. Leucinization has bleached sand and silt grains in the A1 horizon, in most of the A2 horizons in Planosols (Argialbolls) and on surfaces of grainy gray coatings on ped surfaces in the B horizons.

Riecken and Poetsch (1967) have distinguished between cumulative soil genesis and non-cumulative soil genesis. The first process (figure 6) is illustrated by slow deposition of alluvium in small valleys in which upward movement of the solum (A plus B horizons) keeps pace with the thickening of the deposit. Characteristics of the solum fade away below, leaving the material recognizable as C horizon, labeled C^c by Riecken and Poetsch in recognition of the cumulative process. Accelerated erosion on cultivated fields upslope has changed this picture in many places by thickening the A1 horizon above faster than it loses its identity by dissipation of organic matter

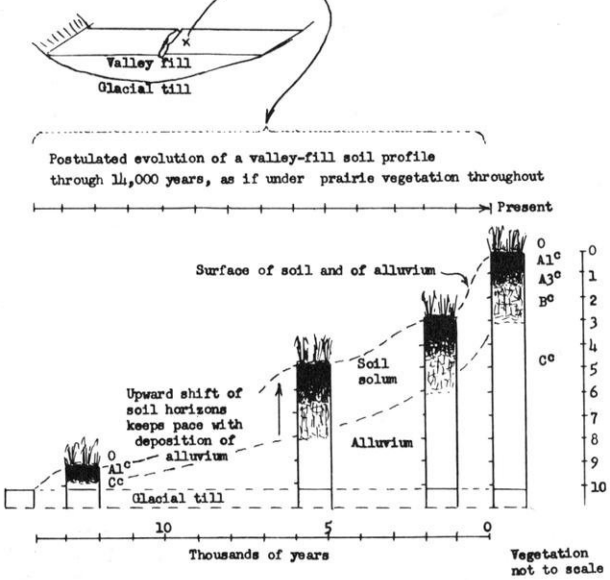

FIGURE 6

below or by burying the nearly black A1 horizon under lighter colored material washed from the upland. Buried dark alluvial soils are exposed in many cutbanks of streams and rivers in the North Central Region of the U.S.A. The second concept, that of noncumulative soil genesis, rules out significant deposition on the surface of the soil in the course of its development. Calcareous materials collapse (figure 2) as a result of leaching of carbonates (Robinson, 1950). The fact that Tama silt loam and other deep soils under prairie are strongly to medium acid clear to the surface indicates that biocycling has not been as effective under prairie as under associated deciduous forest where the A1 horizon is slightly acid to neutral.

These two cumulative and non-cumulative processes are not mutually exclusive in that eolian materials may fall on the soil surface at any time and be washed down the profile by percolating water (Borchardt et al., 1968; Allan and Hole, 1968).

PROCESSES OF SOIL FORMATION UNDER PRAIRIE

(1) *Accumulation and destruction of organic soil horizons on the mineral soil surface.*

The dry weight of a prairie litter in April may amount to 5 tons per acre (11.2 m T/ha) (Nielsen and Hole, 1963). By October it may be reduced by consumption and decomposition to an organic horizon weighing (dry) about 2 tons per acre (4.5 m T/ha). The effect of this organic (01) horizon is to shelter and nourish a complex biota including micro-organisms and rodents, to shield the black mineral soil from direct sunlight, to reduce the rate of evaporation from the mineral soil, to delay the start of the growing season, and to hold back a reserve of plant nutrients in unavailable forms. Prairie fires (Curtis, 1959) alter the situation by exposing to sunlight the nearly black A1 horizon to which charred organic matter has been added, increasing the length of growing season and the range of variations in temperature and moisture content of the soil, and by releasing plant nutrients in quantity in the form of plant ash, by destroying tree seedlings, weed seeds, insects and microorganisms above-ground, and by temporarily evacuating rodents (voles, mice, rabbits) from the area.

(2) *Melanization: Accumulation of organic matter in the surface mineral soil layer (A1 horizon).*

A greater mass of organic matter is incorporated into the mineral soil profile under prairie than under a modern oak forest, which, under fire protection since settlement, has in southern Wisconsin, for example, changed from an open to a closed forest. In Wisconsin the dry weight of the 60-foot-tall (30 m) forest stand may be 90 tons per acre (200 m T/ha) in contrast to the near-by 3-ton (6.7 m T) 10-foot-high (3 m) stand of prairie (Nielsen and Hole, 1963). The organic matter in the soil to a depth of 42 inches (105 cm) amounts to about 80 tons per acre (179 m T/ha) under forest and 150 tons (336 m T/ha) under prairie. Since the volume of a given weight of soil organic matter is two to three times that of an equivalent weight of mineral matter, we are talking about ten to twenty-five percent of the total soil volume in the A1 horizon. Weight of silt-size opal phytoliths, which is to plow depth (7 inches; 18 cm) about 10T/A (22 m T/ha) in prairie soils in Illinois and 3T/A (6.7 m T/ha) in nearby forest soils (Jones and Beavers, 1964) may be considered as inconsequential with regard to plant nutrition.

Root proliferation of *Andropogon gerardi* extends to a depth about 80 inches (200 cm) in Tama silt loam, or 21 inches (60 cm) below the commonly recognized lower boundary of the B horizon (figure 7) (Douglas et al., 1967). The roots are concentrated in the upper two feet of soil where centuries-old residues from them darken the soil. Carbon-14 dates ranging from 300 to 500 years before present for organic matter in the upper six inches (15 cm) of some prairie soils (Broecker et al., 1956), represent averages of modern and old organic matter. If half of the dry root mass of 4 to 5 tons per acre (9 to 11 m T/ha) is replaced each year, the annual contribution of underground parts to the soil organic matter would be 2 to 2.5 tons per acre (4.5 to 5.6 m T/ha). Thorp (1948) estimated nearly a half ton per acre (1.1 m T/ha) of raw organic matter (dry weight) added to the soil annually from roots under big bluestem grass stands. Bray (1963) estimated 1.8 T/a (4 m T/ha) annual below-ground production for herbaceous crops as compared to 1 T/a (2 m T/ha) for forest.

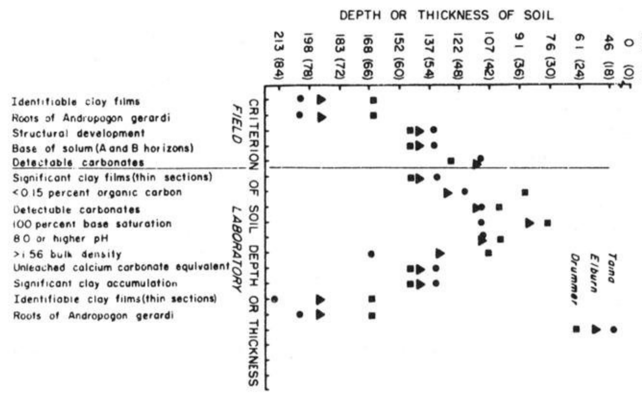

FIGURE 7

Thickness of three Mollisols based on soil properties and depth of root penetration of native big bluestem (Andropogon gerardi) (Douglas, et al. 1967).

An unknown amount of organic matter moves with percolating water down the soil profile from above-ground biotic material, which is produced at an annual rate of about 4 T/a (9 m T/ha) in forest and 2.6 T/a (6 m T/ha) under herbaceous cover as reported by Bray (1963); and 2.6 T (5.7 m T/ha) and 3.0 T (6.7 m T/ha), respectively, according to Nielsen (1963). The quantity moving in percolating water in both forest and grassland soils is probably slight in view of the work of Lunt (1941) which indicates that about 300 pounds of organic matter solids move per acre (336 kg/ha) per year out of the forest litter, a distance of less than 4 inches (10 cm) into the subjacent mineral soil. At the same time about 15 pounds per acre (17 kg/ha) of nitrogen moves in solution from above ground materials into the A horizon. This contrasts with 3 pounds per acre (3.4 kg/ha) of nitrogen lost annually from entire soil profiles under cover of meadow at Coshocton, Ohio (Harold and Dreibelbis, 1951; Dreibelbis, 1946). Joffe (1940) concluded that more than 80% of solutes are removed from the percolating solution and retained in the soil solum (A and B horizons).

One can only conjecture how much organic matter is mixed into soil by earthworms under prairie. Studies are needed of the activity of *Lumbricus terrestris* in pulling prairie litter into soil, and of *Allolobophora caliginosa* (three or four times more numerous than *L. terrestris* in a forest soil) in depositing casts on the surface of the soil and thereby burying litter. Preliminary investigations (Nielsen, 1963) in a deciduous forest in the University of Wisconsin Arboretum indicate that the *L. terrestris* annually incorporates virtually the entire annual crop of leaves (about 7 million per acre; 17 million per hectare) into the A1 horizon of a Gray-Brown Podzolic (Hapludalf) soil. This may account for about three-quarters of the 30 tons per acre (67 m T/ha) of organic matter in that horizon. The remainder may be assumed to come from root residues at a postulated rate of one third ton (Bormann et al., 1968) to one ton per acre (0.7 to 2.2 m T/ha) per year, or about half of the root mass in the 0″–3″ (0–7.5 cm) A1 horizon. The entire root mass may be ¼th that of the total tree mass (Ovington and Madgwick, 1959) or about 30 tons per acre (67 m T/ha), dry weight in an oak forest (figure 3). On a forest plot in which the weight of litter was doubled each autumn, the population of earthworm middens doubled (Nielsen and Hole, 1964). Activity of *L. terrestris* in soils under prairie in the University of Wisconsin Arboretum was not considered to be notable and middens were few. Nielsen's determinations of rates of casting by *A. caliginosa* (about 18 tons, dry wt., of casts per acre or 40 m T/ha) annually under forest and prairie suggest that the activity of these worms is directly proportional to the amount of organic matter in the upper A1 horizon, not on the amount of plant litter on the surface. These considerations leave the impression that earthworms do only a slight amount of actual pulling of plant litter into the A1 horizon under prairie. Ants that make mounds less than about 2 inches (5 cm) in diameter also introduce only a slight amount of organic matter into the A horizon.

Surface deposits of soil in the form of earthworm casts, spoil from rodent burrows and large ant mounds, particularly those a foot (30 cm) or more in diameter, can lead to an increase in thickness of the A1 horizon. The prairie vegetation closes in on surficial deposits and converts the new layer into dark topsoil, whenever faunal activity declines abruptly. This may thicken the A1 horizon at the top faster than the lower portion of the A1 loses its diagnostic color and organic matter content. Earthworm casts may amount to a layer 20 cm thick per century, judging by Thorp (1949). Baxter and Hole (1967) found in the Ipswich prairie in southwestern Wisconsin that the western mound-building ant, *Formica cinerea montana* Emery, is bringing clayey subsoil to the surface at the rate of about one cm per century, enough to influence the surface soil texture of the Tama soil there. In well drained soils subsoil may be carried up by ants from as deep as 5 or 6 feet, or 2 meters (figure 8) and the clay content of the surface soil increased to about the same as that of the subsoil. Shrader (1950) has

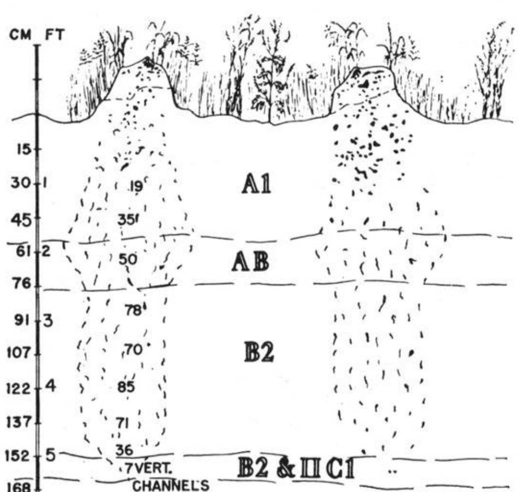

FIGURE 8

Sketch of soil profiles at and between two mounds built by the western mound-building ant (Formica cinerea montana **Emery). Figures under the left-hand mound are the numbers of ant channels observed on the floor of the pit at the depth indicated (Baxter and Hole, 1967).**

shown that with progressively poorer drainage, the contrast between the clayey B horizon and the siltier A horizon increases (figure 9). This might be fostered by the increasing

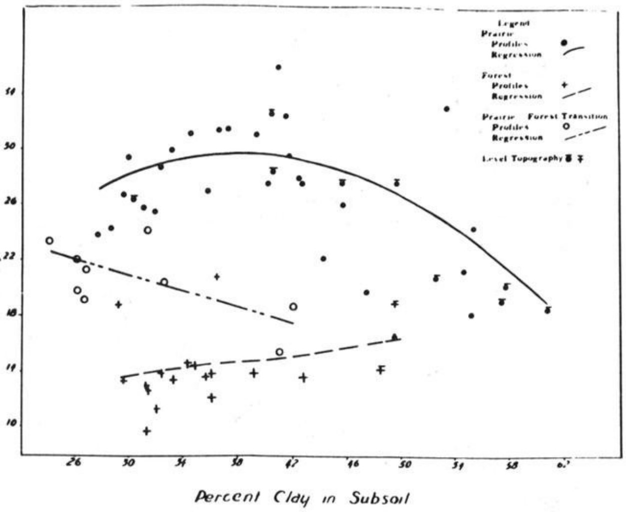

FIGURE 9

Clay contents of surface and subsoils in profiles developed under prairie, forest and prairie-forest transition (Shrader, 1950). Points for well drained soils lie on the left and for Planosols with well developed clayey B horizons, on the right.

limitation by high stand of ground-water of opportunity for deep excavation by the ants. Nests of *Formica cinerea* are shallow and mounds are as much as ten feet (3.3 m) wide on poorly drained soils, in contrast with nests more than 5 feet (1.5 m) deep and mounds a foot (30 cm) high and 1.5 feet (45 cm) wide on deep well drained silty soils.

TABLE 1

Plant species list[1] and frequency[2] for 40 circular plots[3], each one square foot (0.09 m²) in area, Ipswich Prairie, Grant County, Wisconsin, August, 1965.

	Frequency	
Species	*Off ant[4] mound*	*On ant[4] mound*
Agropyron repens	30	100
Ambrosia artemisiifolia	10	—
Andropogon gerardi	10	—
Anemone cylindrica	30	—
Asclepias syriaca	5	—
Aster ericoides	10	—
Aster lævis	5	—
Aster sagittifolius	30	—
Eryngium yuccifolium	5	—
Lactuca biennis	15	—
Panicum virgatum	10	—
Pastinaca sativa	25	—
Physalis virginica	5	—
Poa pratensis	100	100
Prunus serotina	5	—
Ratibida pinnata	15	—
Rosa carolina	10	—
Rubus allegheniensis	15	—
Solidago missouriensis	10	—
Trifolium pratensis	5	—

[1]Additional species not observed in the forty plots but observed within the half-acre tract under study include: *Achillea millefolium, Antennaria plantaginifolia, Asclepias verticillata, Aster lucidulus, Ceanothus americanus, Cirsium dicolor, Desmodium illinœnse, Euphorbia corollata, Helianthus strumosus, Hieracium canadense, Monarda fistulosa, Oenothera biennis, Pyrus iœnsis, Solidago nemoralis, Vitis riparia.* Other species observed in the immediate vicinity of the tract include: *Andropogon scoparius, Fragaria virginica, Oxalis stricta, Petalostemum candidum, Populus tremuloides.*

[2]No frequency value (—) indicates species not found within the observed frequency plots.

[3]Twenty plots were on the mounds and twenty were between mounds.

[4]Mounds of *Formica cinerea montana* Emery.

The steep sides of the nearly one-foot (30 cm) high ant mounds are well covered with sod of Kentucky blue grass (*Poa pratensis*), in the Ipswich prairie in Wisconsin. The periphery of the top of each mound is occupied by quack grass (*Agropyron repens*), as indicated in Table 1. The roots of these two grasses hold the soil in place, restricting erosion, and rapidly stabilizing material slumping or washing off the bare tops of the mounds. One wonders what native prairie plants (possibly *Muhlenbergia cuspidata* or *M. mexicana*) occupied the sides of the mounds before the introduction of *P. pratensis* and *A. repens*.

Content of organic matter decreases gradually with depth in subsoils of most grassland soils. However, secondary organic matter accumulations in the B horizon are common in prairie Planosols (Albolls) and in forest-on-prairie soils associated with Brunizems (Hapludolls) (Riecken, 1965). These accumulations may be presumed to result from eluviation of organic matter from the pale A2 horizon and to root proliferation in the subsoil during droughts when the A horizon was depleted of moisture.

The notable accumulation of organic matter in soils under prairie locks up large quantities of plant nutrients, including phosphorous, making them unavailable to plants. Available phosphorous contents as low as one ppm characterize virgin Tama silt loam (A1 and B1 horizons). This is in contrast to 82 ppm in the tops of ant mounds in August (Baxter and Hole, 1967).

(3) Structure formation in the A1 horizon

Soil structure is granular in mollic epipedons that are coarser in texture than silty clay loam, and is fine subangular blocky in finer textured material. Soils with more than 50% by volume occupied by earthworm casts and earthworm channels are called Vermudolls (Soil Survey Staff, 1967), in accordance with the finding of Buntley (1960) who used the term Vermisol for worm-worked Chernozems in eastern South Dakota. Bulk densities between 0.8 and 1.2 are common respectively in A and B of silty Brunizem and Planosol (Alboll; Albaqualf) sola. Wet-dry, shrink-swell, freeze-thaw and root expansion-root decomposition cycles in clayey A1 horizons foster the blocky structure. Prairie vegetation pumps available water out of a soil to a depth of several feet (a meter or two) (Watterston, 1966). Granular structure is formed by the passage of soil material through earthworms, as already mentioned; by microbial production of soil-binding gums and other materials from biotic tissues (Harris, et al., 1966); by formation of sesquioxide colloidal masses through weathering of primary minerals and mineralization of organic matter; by coagulation of humates by carbonates; by formation of binding organo-clay complexes; by knitting together of soil particles and aggregates by interlacing roots, some of which pierce the peds.

(4) Eluviation-Illuviation: Leaching of carbonates and bases

Most soils formed under prairie were developed from calcareous materials such as loess, glacial till, outwash, lacustrine deposits, and shales. Leaching of carbonates and bases has brought about a collapse of the column of mineral material (figure 2) in proportion to the original content of carbonates (Robinson, 1950), and a reduction of pH from 8.5 in calcareous initial material to 5.5 in a mature Brunizem (Hapludoll, Argiudoll). Accumulation of calcite and gypsum in Cca and Ccs horizons is notable in the vast drier portions of the prairie triangle west of the Brunizem (Udoll) section (Aandahl et al., 1960) and locally in western parts of the zone of Brunizems. In the zone of Chestnut and Brown soils silica is a notable component of cement in petrocalcic layers (Fosberg, 1965). Gypsum occurs as discrete crystals, for the most part. Calcite is (a) finely disseminated in clayey soil, (b) in threads and filaments and films in soils of medium texture with numerous fine pores and fractures, and (c) in blotches or spots in soils of medium texture with large voids. Sesquioxides move down with some organic matter and clay. Manganese moves farther than iron. Bleached A2 (Albic) horizons are present in prairie Planosols (Argialbolls) (Smith, et al., 1950).

(5) Structure formation in the B horizon

A structural and/or textural B horizon is so common in medium textured soils under prairie that pedologists do not feel it necessary to ascribe their presence in every case to previous development of the same soil profile under forest. In any case, shrink-swell cycles of the clayey material, in the absence of abundant organic matter and much earthworm and other faunal activity, account for the formation of three or more sets of joint-cracks, defining the peds. Wedging by plant roots shapes peds, and swelling of subsoil peds in wet seasons flattens roots. Where shrinking and swelling are excessive, as in Grumusols (Vertisols), lenticular structure and slickensides on ped surfaces are developed. Burrowing by cicada nymphs produces a particular kind of subangular blocky structure (Hugie and Passey, 1963). Abandoned rodent burrows quickly fill with A1 horizon material and are then referred to as krotovinas.

Prismatic structure is well developed in soils subject to droughts and relatively free from activity of cicadas and earthworms. Hence Chestnut Brown and Sierozem soils have the more strikingly developed prismatic structure than do Brunizems and Chernozems.

(6) Formation and migration of high cation exchange capacity clay; and formation of iron oxide nodules and concretions, and grainy ped coatings

We may stress the fact that soils developed under prairie have formed from unconsolidated materials. Thorp (1948) estimates that in about 30% of the area of the original grasslands of the United States soils have formed from soft shales, silt-stones and sandstones, and in the remaining 70% of the grassland the soils have formed from deposits made by glacial ice, lakes, streams, wind and mass-wasting. Probably loess is the most extensive initial material of soil under prairie the world over, glacial till second in importance, and wind-and-water-laid sands, third. Comminution of bedrock has already taken place before the time-zero of most grassland soils. We do not find prairie soils formed from granite bedrock, or any other hard rock for that matter. The weathering that occurs in prairie soils largely concerns sand, silt and clay-size particles of the initial materials.

New silicate clays of high cation-exchange capacity (montmorillonite, vermiculite, chlorite) form in these soils by weathering of fine silt-size and clay-size silicates, and synthesis of clay from silica, alumina and various cations released by decomposition of organic matter. Glenn et al. (1960), found evidence that clay-size chlorite and amorphous material had formed in increasing amounts with proximity to the surface of a Tama silt loam. The new clay material is added to the more abundant clay already present in the original loess or other unconsolidated deposit. Increments of eolian clay are deposited on the soil surface in many areas, during the millenia of soil development, and washed down into the B horizon (Borchardt et al., 1968).

Clay skins (called argillans by Brewer, 1964) and associated films of iron oxides and organic matter form on ped surfaces in the B and upper C horizons (Buol and Hole, 1961). These are best developed in forest soils on well drained sites over calcareous geologic materials of coarser texture than the solum, but are recognized widely in soils under prairie. The cutans appear to be depositional from colloidal suspensions of percolating waters. The fine material was washed out of the A horizon (figure 4) into the B and C horizons. Some of the cutans are formed by pressure during periods of wetting and swelling of blocky clayey B horizons.

Iron is released from primary silicates, from films and grains of iron oxide and from organic matter by processes of decomposition, and is redistributed in the soil profile. This may be largely within the solum, where iron concretions and nodules form, particularly in soils subject to many cycles of wetting and drying. Mottles of iron oxide form in lower sola of well drained soils and in B and C horizons of poorly drained soils. In the latter reduction of iron and/or removal of iron from the solum favors development of a gley horizon.

Grainy ped surfaces are light gray sandy and coarse silt coatings (skeletans of Brewer) formed in A2 and B horizons of forest soils (Hapludalfs) but present as relics in subsoils of some prairie soils (Hapludolls) (right hand side of figure 1) (Arnold and Riecken, 1964). These coatings are of bleached mineral grains, mostly of quartz, and probably represent both sedimentary microdeposits washed down the profile, and lag residues on ped (soil structural block) surfaces. Where erosion stripped soils from slopes, as in north central Iowa between 13,000 and 3,000 years B.P., grainy ped coatings are absent from subsoils (Walker, 1966).

(7) Formation of irregular microtopography

The surface of the ground in undisturbed grasslands is irregular on a small scale, as compared with the surface of land that has long been under cultivation. The microrelief of natural soil surfaces is produced by faunal activity, already referred to earlier in this paper; by heaving, by frost action, and, in clayey soils, by expansion of clay; by removal of soil by wind, water and fauna from bare areas (sometimes leaving a pebble mulch behind) between plants and clumps of vegetation and deposition of some of this material among and around plant stems; and by wedging of soil masses by growing roots of some of the forbs of the prairie.

Conclusion

Conditions for development of soils under prairie vegetation in North America have been made possible by various geologic, climatic, and biologic factors, including man (Weaver, 1954). Wind, water and glacial ice laid down most of the necessary unconsolidated, calcareous initial mineral materials. Orogenies raised the mountain barriers which altered the global wind patterns in such a way as to form a triangular climatic region characterized by summer droughts and thunder storms with lightning that can start fires. A great variety of plants and animals migrated into the region from north and south. Farmers from Europe displaced the aborigenes and over most of the prairie triangle replaced the natural grassland flora and fauna with a few species of crops and livestock. Remnants of the original grassland communities can be found in various degrees of completeness along railroad tracks, in undisturbed wetlands, and borders of cemeteries, and in wildlife preserves and parks. Man's influence on the prairie biotic community, therefore, has been important. His effect on the soil (Bidwell and Hole, 1965) has been enormous by removal of most of the native plants and animals that were active in the soil; through reduction in content of organic matter, increase in bulk density by compaction under machinery and livestock in A horizons of most cultivated soils; smoothing the soil surface with or without furrowing and ditching; exposure of the soil at intervals to direct sunlight and to wind and water erosion; further alteration of microclimate by drainage and irrigation; and in some places, total disruption of the soil profiles and landscapes by strip mining for coal, as in the vicinity of Galesburg, Illinois. Under remnants of prairie biotic communities and in places where prairies have been re-established, soil-forming processes function much as they did for thousands of years past. New man-induced contaminants, both radioactive and nonradioactive, are now unavoidably a part of the pedogenic cycle and hence the soil system cannot be quite the same as it was three centuries ago.

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Characteristics of Dark Colored Soils Developed Under Prairie in a Toposequence in Northwestern Illinois

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A toposequence of soils developed under native prairie vegetation was sampled and studied in 1962 which was near Oneida approximately 12 miles northeast of Galesburg in Knox County, Illinois. (Twp. 13N, R3E, Sec. 31, SW160).

The study area is located in the Tall Grass native vegetation region of North America which Transeau (1935) called the Prairie Peninsula. Big bluestem (*Andropogon gerardi*) is considered to be the prevailing native prairie grass present during the formation of these soils. A native vegetation map of Illinois prepared by Fehrenbacher and Alexander (1958) from soil surveys and based largely on surface soil color is in very close agreement with the Illinois part of Transeau's Prairie Peninsula map.

This dark colored, prairie toposequence of soils is developed in about 15 feet of loess. Samples for physical and chemical analyses were collected to a depth of 5 feet. Abbreviated soil descriptions are presented in Table 1 and physical and chemical properties are given in Table 2.

TABLE 1

Abbreviated Soil Descriptions

TAMA	
A1, 0–11 in.	10YR 2/2, silt loam to light silty clay loam, granular, friable, clear smooth boundary, roots abundant.
A3, 11–15 in.	10YR 3/1, silty clay loam, granular, friable, clear smooth boundary, roots abundant.
B1, 15–20 in.	10YR 3/2, silty clay loam, subangular blocky structure, firm, clear smooth boundary, roots abundant.
B21, 20–28 in.	10YR 4/3, silty clay loam, mottled with 10YR 5/2 and 10YR 6/2, prismatic structure breaking to subangular blocky, clay coatings, firm, clear smooth boundary, few iron concretions, roots common.
B22, 28–36 in.	10YR 5/4, 5/6, 5/8 and 6/2 mixed and mottled, silty clay loam, prismatic structure breaking to subangular blocky, clay coatings, firm, gradual smooth boundary, many iron concretions, roots common.
B3, 36–44 in.	10YR 5/4, light silty clay loam, mottled with 10YR 6/2 and 5/8, angular blocky structure, clay coatings, firm, gradual smooth boundary, many iron concretions, no roots.
C1, 44–60 in.	10YR 5/4, heavy silt loam, mottled with 10YR 6/2 and 5/8 massive with occasional verticle jointing, friable, many iron concretions, no roots.
NOTES:	Loess 182 inches thick, site in bluegrass sod, moderately well drained.
MUSCATINE	
A1, 0–11 in.	10YR 2/1, silt loam to light silty clay loam, granular, friable, clear smooth boundary, roots abundant.
A3, 11–17 in.	10YR 2/1.5, silty clay loam, granular, friable, clear smooth boundary, roots abundant.
B1, 17–25 in.	10YR 3/1 to 3/2, silty clay loam, mottled with 10YR 5/2, granular, common iron concretions, roots common.
B21, 25–32 in.	10YR 4/2, silty clay loam, mottled with 2.5Y 5/2 and 5/8, subangular blocky structure, clay coatings, firm, clear smooth boundary, common iron concretions, roots common.
B22, 32–38 in.	2.5Y 5/2, silty clay loam, mottled with 2.5Y 6/2 and 5/4 and 10YR 5/8, subangular to angular blocky structure, clay coatings, firm, clear smooth boundary, numerous iron concretions, roots occasional.
B3, 38–53 in.	Mixed 2.5Y 5/2 and 5/4, light silty clay loam, mottled with 10YR 5/8, angular blocky structure with tending to prismatic, clay coatings, firm, gradual smooth boundary, numerous iron concretions, roots occasional.
C1, 53–60 in.	2.5Y 5/2, heavy silt loam, mottled with 2.5Y 5/4, 10YR 5/8 and 5YR 4/8, massive with a tendency to angular blocky, friable, numerous iron concretions, roots occasional.
NOTES:	Loess 175 inches thick, site in bluegrass sod, somewhat poorly drained.
SABLE	
A1, 0–14 in.	10YR 2/1, silty clay loam, angular blocky to granular structure, friable, gradual smooth boundary, roots abundant.
B1, 14–19 in.	10YR 3/1, silty clay loam, mottled with 10YR 3/2, granular, clay coatings, firm, clear smooth boundary, roots abundant.
B21, 19–27 in.	2.5Y 5/2 to 5Y 5/2, heavy silty clay loam, mottled with 2.5Y 5/6 and 10YR 5/8, angular blocky with a tendency to prismatic structure, clay coatings, firm, clear smooth boundary, roots abundant.

B22, 27–37 in.	2.5Y 5/2 to 5Y 5/2, silty clay loam, mottled with 2.5Y 5/6 and 10YR 5/8, prismatic breaking to angular blocky structure, clay coatings, firm, gradual smooth boundary, roots common.
B3, 37–43 in.	2.5Y 5/2, light silty clay loam, mottled with 2.5Y 5/6 and 10YR 5/8, prismatic breaking to angular blocky structure, clay coatings, firm, gradual smooth boundary, roots common.
C1, 43–49 in.	Mixed 2.5Y 5/2 and 2.5Y 5/6, heavy silt loam, mottled with 10YR 5/8, massive, friable, clear smooth boundary, roots occasional.
C2, 49–60 in.	2.5Y 6/2, silt loam, mottled with 2.5Y 5/4 and 7.5YR 5/8, massive, friable.
NOTES:	Loess 176 inches thick, site in bluegrass, poorly drained.

TABLE 2

Physical and Chemical Properties of Tama, Muscatine, and Sable Soils

Horizon	Depth Inches	Sand 2-0.5 mm. %	Silt .05-.002 mm. %	Clay .002 mm. %	Organic Matter %	Organic Matter Tons Per Acre/Inch	pH	Base Saturation %	Cation Exchange Capacity me/100 g.	Ca/Mg Ratios	Exchangeable Cations me/100 g. soil: Ca	Mg	K	Na
						TAMA								
A1	0-11	1.9	68.5	29.6	5.3	6.9	5.8	78	25.4	3.5	13.1	3.8	3.0	0.1
A3	11-15	1.7	65.8	32.5	3.2	4.2	4.9	59	23.1	2.3	9.0	4.0	0.7	0.1
B1	15-20	1.8	64.0	34.2	2.4	3.4	4.9	63	23.5	1.8	9.2	5.0	0.5	0.1
B21	20-28	1.8	61.6	36.6	1.2	1.7	5.1	76	26.9	1.7	12.4	7.3	0.5	0.1
B22	28-36	1.6	64.2	34.2	0.5	0.8	5.4	81	25.2	1.7	12.5	7.5	0.4	0.1
B3	36-44	1.3	68.7	30.0	0.5	0.8	5.6	86	22.4	1.5	11.4	7.5	0.3	0.1
C1	44-60	1.3	72.2	26.5	0.3	0.6	6.0	90	19.5	1.5	10.4	6.8	0.2	0.1
						MUSCATINE								
A1	0-11	1.7	67.0	31.3	5.7	6.9	5.9	80	27.7	3.9	17.0	4.4	0.6	0.2
A3	11-17	2.3	64.7	33.0	3.5	4.6	5.5	69	25.4	2.6	12.3	4.8	0.3	0.2
B1	17-25	2.0	63.6	34.4	2.3	3.2	5.6	77	26.1	2.2	13.3	6.2	0.3	0.1
B21	25-32	2.0	61.4	36.6	1.1	1.6	5.8	86	27.6	1.8	15.1	8.4	0.3	0.2
B22	32-38	1.7	62.6	35.7	0.7	1.0	6.1	90	27.2	1.7	14.8	9.0	0.4	0.2
B3	38-53	1.5	67.4	31.1	0.4	0.6	6.7	97	23.5	1.6	13.8	8.4	0.3	0.2
C1	53-60	1.4	72.2	26.4	0.3	0.5	7.0	100	20.2	1.6	12.2	7.7	0.3	0.2
						SABLE								
A1	0-14	2.1	64.1	33.8	4.9	7.2	5.7	82	31.6	3.2	19.3	6.1	0.4	0.1
B1	14-19	3.1	61.2	35.7	2.4	3.7	5.5	81	29.8	2.5	16.9	6.7	0.4	0.1
B21	19-27	3.5	59.8	36.7	1.1	1.6	5.6	84	30.3	2.2	17.2	7.8	0.4	0.2
B22	27-37	1.8	66.0	32.2	0.4	0.6	6.2	95	25.6	2.1	16.0	7.8	0.4	0.2
B3	37-43	1.5	68.9	29.6	0.3	0.4	6.8	100	23.8	2.1	15.8	7.7	0.3	0.2
C1	43-49	1.4	71.9	26.7	0.2	0.3	7.2	100	21.4	2.1	14.2	6.8	0.3	0.1
C2	49-60	1.4	78.0	20.6	0.1	0.0	calc.	-	-	-	-	-	-	-

Tama, the well to moderately well drained soil, occurred somewhat below the highest elevation on the slope. Muscatine, the somewhat poorly drained soil, occurred on a less sloping position at an intermediate elevation, and Sable, the poorly drained soil occurred on a level to depressional area farther downslope at the lowest elevation. Geomorphologically, each of the three sampling sites may be considered as constructional in nature; that is, soil material from higher ground is added to each site by geologic erosion. The Tama site is thought to be more or less balanced in that as much material is added as is eroded downslope. The Muscatine site will have a little more material added than is eroded to the lower Sable position, and the Sable site would have considerable material added but little or no material removed by erosion. Figure 1 illustrates the landscape position occupied by these three soils.

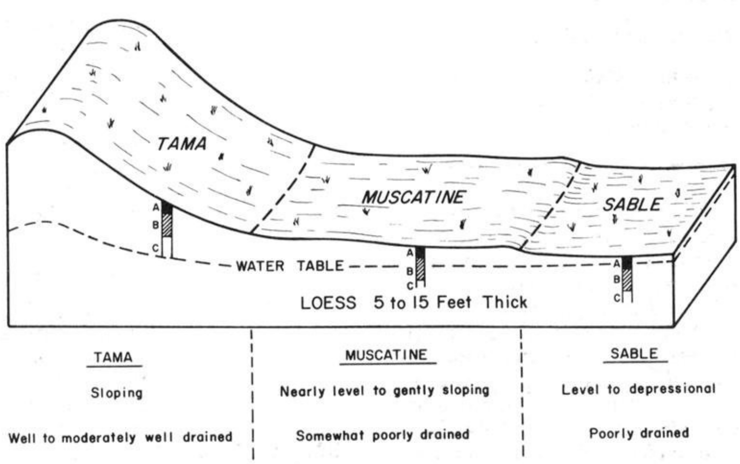

FIGURE 1

Landscape Diagram of Muscatine, Tama, and Sable Soils

All the soils in the toposequence are classified as Mollisols in the New Classification System (Soil Survey Staff, 1960). Briefly Mollisols have surface soil horizons that are 10 or more inches thick and have colors darker than a value of 3.5 on Munsell color charts. Base saturation must be more than 50% with pH values ranging from medium to high. Moderate to strong structure is also required in the surface layers.

Previous to the New Classification System, these soils were classified as Prairie Soils as outlined in Soils and Men, the U.S.D.A. 1938 Yearbook of Agriculture (Baldwin, Kellogg and Thorp, 1938). Brunizem is another name that has been applied to dark colored soils developed under prairie vegetation (Siminson, Riecken and Smith, 1952). The role of grass vegetation in soil development is described by Thorp (1948) and Kellogg (1948). Organic matter and dry matter production are discussed in relation to the various climates occurring in the world.

Following are a few general properties of the loess parent material. At the sampling locations the thickness was approximately 15 feet, leached to 85 inches in the Tama, and to 95 inches in the Muscatine and Sable. Particle size distribution in % sand, silt and clay of the parent loess may be noted in the C horizons of the profiles in Table 2. Montmorillonite is the major clay mineral component of the loess with very small amounts of other clay minerals such as vermiculite, kaolinite, illite and chlorite (Beavers, Johns, Grims and Odell, 1955).

The percent organic matter content with depth in these three soils is shown in Table 2. The percent organic matter in the Muscatine soil remains highest to a depth of 60 inches. Calculated on a weight basis to a depth of 60 inches, as tons per acre, the organic matter is highest in the Muscatine (159.6 tons per acre) with Tama (144.7 tons per acre) and Sable (142.9 tons per acre) being nearly equal (Fig. 2C).

The percentage of clay (<2 u) is shown in Table 2. Surface horizon clay contents range from 29.6% in Tama, to 31.3% in Muscatine, and 33.8% in Sable. The clay content in the zone of maximum accumulation (B horizon) is 36.6% in Tama and Muscatine and 36.7% in Sable. The clay maximum occurs at 25 inches in the Tama and Sable and at 30 inches in the Muscatine. Solum thickness is also greater in the Muscatine as compared to Tama and Sable.

Reaction profiles (Fig. 2A) indicate that the surface horizons of the three soils are at or near a pH of 6. They decrease to approximately 5.0 to 5.5 in the B horizon, and then increase to the lower C horizons which are calcareous. Tama was calcareous at 85 inches, and both Muscatine and Sable were calcareous at 95 inches. Tama had the lowest pH throughout its profile with Muscatine and Sable having similar pH values to a depth of about 25 inches, below which the Muscatine maintains a slightly lower pH.

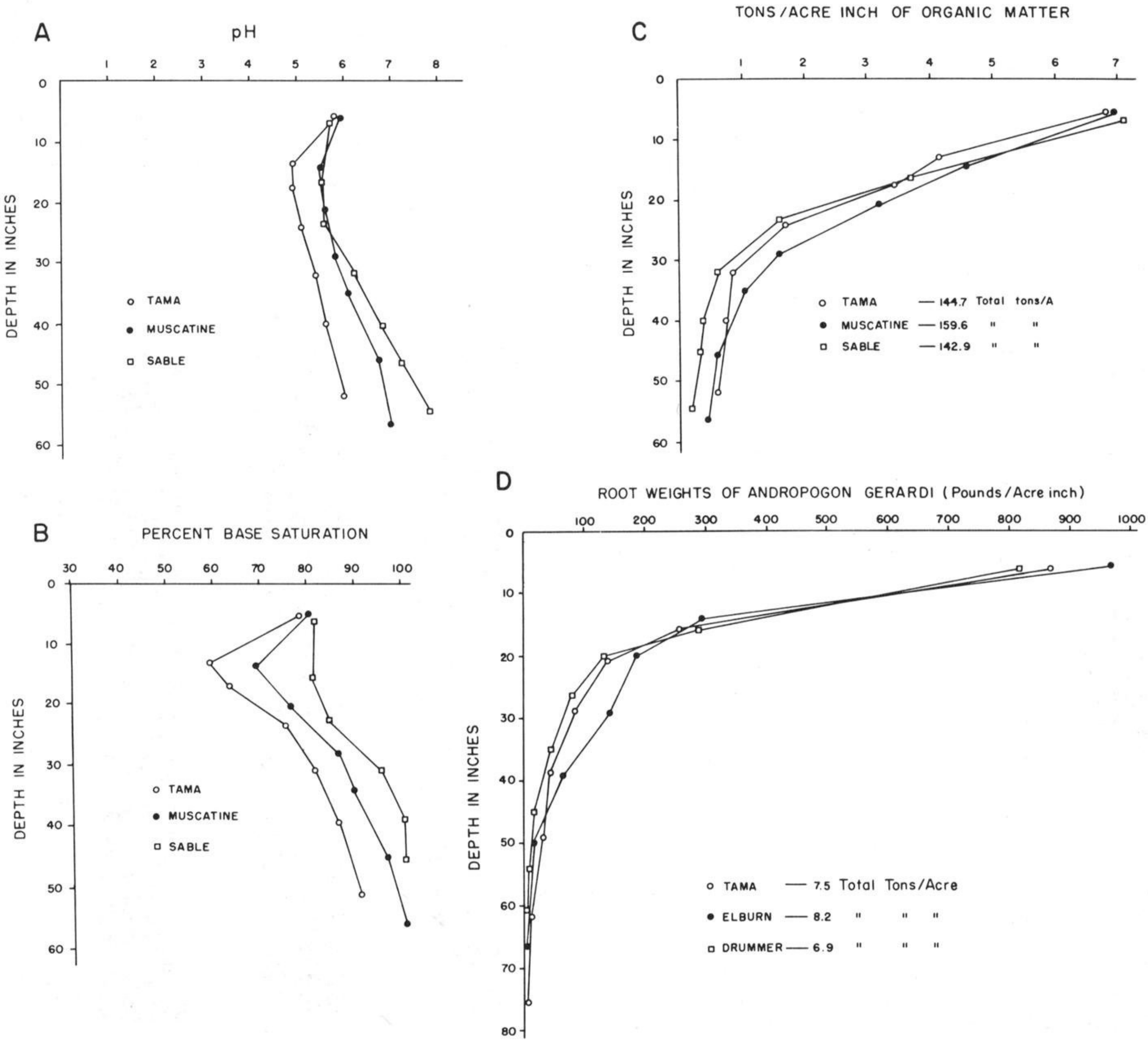

FIGURE 2

Selected Properties of Dark Colored Loess Soils

Percent base saturation with depth for the three soils is shown in Fig. 2B. The exchange complex is dominated by the elements Ca, Mg, K and Na (Table 2). As these bases are removed from the exchange complex either by leaching (weathering) or by plant roots, hydrogen replaces them and consequently the pH of the soil is lowered. There are similarities between the graphs for pH and percent base saturation. Base saturation (Fig. 2B) is lowest throughout the profile in Tama, intermediate in Muscatine and highest in Sable.

The lowest base saturation in all these profiles is in the 12 to 15 inch depth zone. The higher base saturation above this zone may be attributed to the cycling of bases by plants. At the same time weathering and leaching is quite active in 12 to 15 inch zone, moving Ca, Mg, K and Na downward in the soil profile. Since the loess parent material contains free calcium and magnesium carbonates, the base saturation in the lower parts of the profile is 100 percent or more.

Type and amount of clay minerals and organic matter content are primarily responsible for cation exchange capacity, with clay content being most important because exchange capacity values (Table 2) most closely parallel clay content with depth. In comparing the upper 25 inches of all three profiles, the cation exchange capacity increases as the clay content increases. Exchange capacities in the surface horizons show the combined effect of organic matter and clay. The B horizon of Tama has a higher exchange capacity than the surface and differs in this respect from the other profiles. Calcium is by far the most prevalent cation (Table 2) on the exchange complex, being 2 to 3 times greater than magnesium, the next most prevalent cation. Potassium and sodium occur in much smaller amounts.

The ratio of exchangeable calcium to exchangeable magnesium (Table 2) can be used as an indication of soil development. Magnesium is held more tightly than calcium of the exchange complex, and as weathering progresses magnesium will become more abundant in relation to calcium. Lower ratios indicate a greater degree of weathering. Using this parameter Tama is more highly weathered than Muscatine, and Muscatine more highly weathered than Sable. The Ca:Mg ratio curves are similar to the pH and base saturation curves.

Douglas, Fehrenbacher, and Ray (1965) collected roots from *Andropogon gerardi* in DeWitt County, Illinois on a toposequence of soils similar to Tama, Muscatine and Sable. Both sets of soils have solums in loess. The soil series and loess thickness at the DeWitt County site was Tama 71 inches, Elburn 56 inches, and Drummer 41 inches. Since the great majority of roots occurred in the loess portion of these soils, it is probable that similar results would be obtained at the Knox County site. Root distribution and weights are shown in Table 3. 70 to 75 percent of the roots occur in the upper 12 to 13 inches of the soil. Figure 2D shows the root weight in lbs. per acre inch plotted with depth of rooting for each soil. Tama had roots to 80 inches, Elburn to 76 inches and Drummer 65 inches. Also shown on the same graph is the total amount of organic matter per acre calculated to the rooting depth in each soil. The Elburn soil—comparable to Muscatine—had the highest tons per acre—8.2 versus 7.5 for Tama, and 6.9 for Drummer. Drummer compares to Sable in the toposequence. The important point here, we feel, is that since the somewhat poorly drained soil in the intermediate topographic position has the highest content of *Andropogon gerardi* roots, more organic matter was produced. Fig. 3 shows *Andropogon gerardi* roots from 4 inch by 12 inch soil sections, washed and mounted on panels.

TABLE 3

Root Distribution of Big Bluestem (Andropogon gerardi) **in Tama, Elburn, and Drummer Soils**

		Root weights—4 x 12 inch tray with depth		
Horizon	*Depth inches*	*total in horizon gms*	*per inch gms*	*Proportion in horizon %*
		TAMA		
A1	0-13	39.2	3.02	75.4
B1	13-18	4.4	0.89	8.5
B21	18-24	2.8	0.48	5.5
B22	24-33	2.5	0.28	4.8
B31	33-44	1.6	0.15	3.1
B32	44-53	0.9	0.10	1.7
C1	53-71	0.5	0.03	0.9
IIC2	71-80	0.1	0.01	0.1
	TOTAL	52.0		100.0
		ELBURN		
A1	0-12	40.3	3.36	70.0
B1	12-16	4.1	1.02	7.1
B21	16-24	5.1	0.64	8.9
B22	24-34	5.0	0.50	8.7
B31	34-44	2.3	0.23	4.0
B32	44-56	0.6	0.05	1.1
IIC1	56-76	0.1	0.01	0.2
IIC2	76-82	-	-	-
	TOTAL	57.5		100.0
		DRUMMER		
A1	0-13	36.8	2.83	76.3
B21	13-18	5.0	1.00	10.3
B22	18-23	2.3	0.46	4.7
B31	23-30	1.9	0.27	3.9
B32	30-40	1.5	0.15	3.2
IIB33	40-50	0.5	0.05	1.1
IIB34	50-58	0.2	0.02	0.4
IIC1	58-65	0.1	0.01	0.1
	TOTAL	48.3		100.0

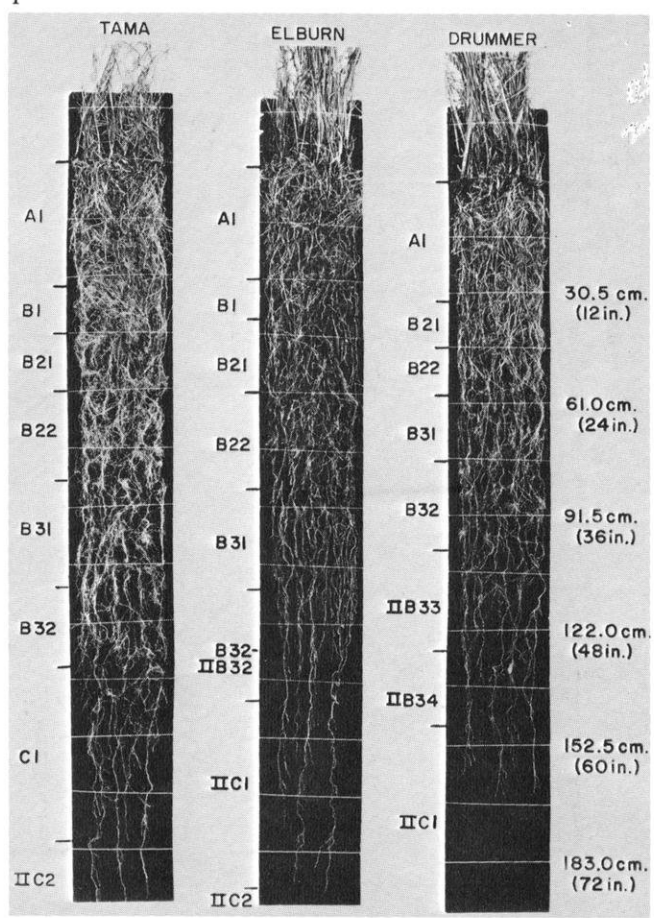

FIGURE 3

Root Distribution of Big Bluestem (Andropogon gerardi) **in Tama, Elburn, and Drummer Soils**

The content of opal phytoliths in the mineral fraction of the soil varies in relation to native vegetation. Opal phytoliths are the siliceous forms of plant cells that remain in the soil long after the organic portion of the cell has decomposed. Content of opal in soils today is a reflection or function of past kind and amount of native vegetation. Grasses produce more opal phytoliths than trees. Jones and Beavers (1964a, 1964b) found surface horizons of soils developed under native prairie grasses had .5 to 3 times more opal than soils developed under native forest vegetation. Some representative contents of opal for loess soils were: prairie soils .85% by weight, intergrade to forest soils .65% by weight, and forest soils .33% by weight. Although not conclusive, the fact that the intergrade soils have an opal content more like the prairie soils than the forest soils, gives some evidence to the proposition that under the present climate the forest is encroaching on the prairie in undisturbed conditions in Illinois.

They further found a difference in opal content of the A horizons in several samples each of Tama, Muscatine and Sable soils. Percent opal by weight in the coarse silt (20–50 u) size fraction was .65 for Tama, 1.11 for Muscatine, and .46 for Sable. Interpretations of these values indicates that the Muscatine soil, somewhat poorly drained and occupying the nearly level intermediate position on the landscape had the highest total dry matter production of the three soils studied.

The Tama, Muscatine, and Sable soils have favorable physical and chemical properties for plant growth and are among the most productive soils in Illinois. The fact that the somewhat poorly drained prairie soils, such as Muscatine, developed on the intermediate position on the landscape have conditions most favorable for the highest production of dry matter should be emphasized. The somewhat poorly drained, nearly level to gently sloping soils not only have the highest total organic matter content, the highest root weight of *Andropogon gerardi*, and the highest content of opal phytoliths in the surface horizons, but also have the highest yields of grain crops under modern agriculture practices.

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Session on: **ASSOCIATED ORGANISMS**

Session Moderator: **DAVID ARCHBALD**

Managing Director of the Arboretum and Wildlife Refuge, University of Wisconsin, Madison

Effects of Fire on Small Mammal Populations in a Restored Tall-Grass Prairie

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Introduction

This paper constitutes an initial report on an investigaiton of the effects of fire on small mammal populations in restored tall-grass prairie. There is considerable information available on effects of fire on western rodent populations (Cook, 1959; Gashwiler, 1959; Lawrence, 1966; Tevis, 1956) but very little is known about effects of burning on small mammals in the higher rainfall grasslands that occurred in the region known as the prairie peninsula. Most of this kind of grassland community has been eliminated by intensive agricultural use, hence few areas are available to study prairie organisms, their habitat and the effects of ecological factors such as periodic drought and fire. Therefore, this study was initiated to investigate small mammal survival and response to fire, at both the individual and population level.

Study Area

The study area is a seven-acre restored prairie on the Knox College Biological Field Station, located 20 miles east of Galesburg, Knox County, in west-central Illinois. This area gets between 30 and 40 inches of precipitation a year. The original vegetation of this county consisted of extensive tall-grass prairies in the north part of the county, inter-fingering with oak-hickory forests to the South in the more dissected land of the Spoon River drainage. The Knox Field Station is located where the original high prairie area begins to be dissected by small streams draining into the Spoon River. The soils found there are upland timber types with a high clay content. Thus, it is an area where oak-hickory forest formerly met and inter-fingered with prairie. Such a mixture of habitats is presently being recreated by the prairie restoration efforts on the field station. The seven acre study area, formerly cropland, was planted to native prairie grasses and forbs in 1955. By the time this study began the prairie vegetation was well established, the dominant grasses being big bluestem (*Andropogon gerardi*) and Indian Grass (*Sorghastrum nutans*) in about equal amounts, with prairie switchgrass (*Panicum virgatum*) and little bluestem (*Andropogon scoparius*) also well represented as sub-dominants. The following prairie forbs are also well represented in the study area: *Desmodium canadense, Desmodium illinoense, Dodecatheon meadia, Eryngium yuccifolium, Euphorbia corollata, Gentiana flavida, Heliopsis helianthoides, Hypericum sphaerocarpum, Ratibida pinnata, Silphium terebinthinaceum, Thalictrum dasycarpum, Tradescantia ohiensis.*

The seven acre study area known as the East Prairie is somewhat isolated from other tracts of grassland, being bordered by a deep lake to the north, by oak-hickory forest to the east and south, and by a brushly swale to the west. (Figure 1.)

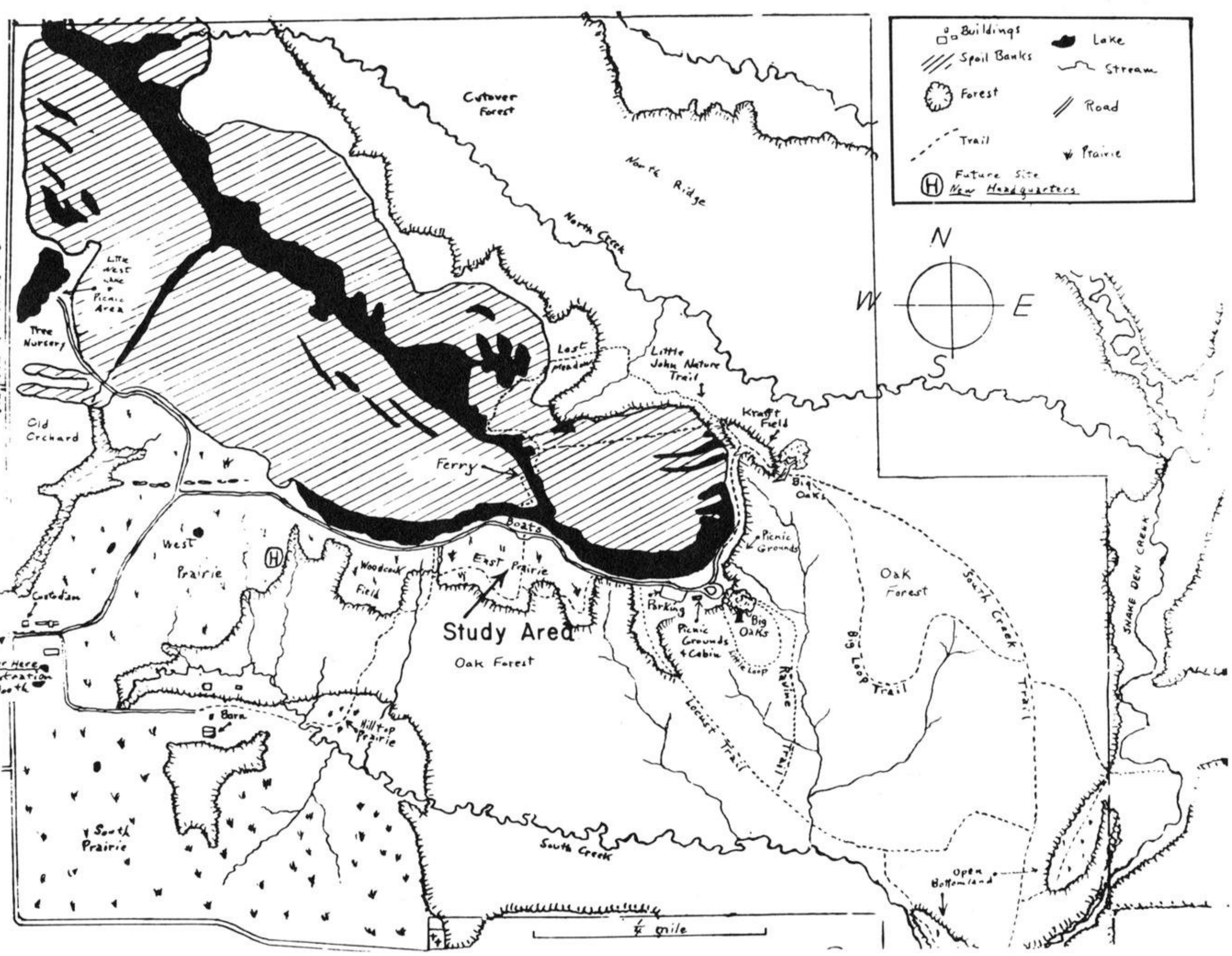

FIGURE 1

Methods

The burning of the study area was carried out in the early spring, late March or early April. Control "lanes" were rotary-mowed around the area to be burned. Students with wet burlap mops and back tanks kept the fire within the predetermined boundaries. Mammal population densities were estimated by livetrap, mark, and recapture methods, using a 64 station, 15 foot interval grid 105 ft. square. The English-made Longworth Small Mammal Trap was used successfully for all species encountered. Trapping procedures included extensive pre-baiting with sunflower seeds for one week or more, followed by intensive, continuous trapping in order to get all trapable mammals marked. Individuals were toe-clipped and ear-tagged for recognition. The average distance between successive captures was calculated and added as a grid boundary strip to determine the actual area being sampled.

Procedures and Results

First Phase of the Study

The initial phase of this study was to determine the immediate effects of a spring fire on the resident mammals of the prairie habitat. In early March of 1966, Grid 1 was set up in the East Prairie and intensively trapped to determine early spring pre-burn densities. The most common small mammals present were two species of voles, the eastern meadow vole, *Microtus pennsylvanicus* and the prairie vole *M. ochrogaster*. Data for this trapping period is presented in Table 1. The short-tail shrew, *Blarina brevicauda* and the western harvest mouse *Reithrodontomys megalotis* were also encountered on the grid but in such low numbers that densities were not determined for them.

After the trapping, all of the East Prairie was burned on March 28. It was a hot, fast fire which consumed large portions of the area in a matter of minutes. Careful observations were made to detect rodents fleeing from the flames. This was particularly well monitored on the gravel road bordering the north side of the burn (Figure 2).
Only five voles were observed fleeing the flames. The fire seemed to effectively eliminate all plant cover above ground. On the day following the fire, a careful search of the burn by a group of students did not turn up a single charred remains of any rodent. Live trapping in and around the edges of the burn was resumed four days later. No animals were captured in the burn. A very few marked and a few unmarked individuals were captured around the unburned grassy edges of the area. The capture sites of these marked individuals are indicated in Figure 2. During this same period, a few selected burrow systems were carefully excavated to detect sub-surface mortality. No animals were found, dead or alive.

TABLE 1

Pre-burn Microtus **Densities, Spring 1966**

		Density		Average Distance Between Successive Captures
		Per Acre	Per 10,000 sq. feet	
Microtus pennsylvanicus	♂	116	26.7	25 ft. (N=18)
	♀	60	13.8	31 ft. (N=7)
	Total	176		
Microtus ochrogaster	♂	68.3	15.7	51 ft. (N=11)
	♀	32.4	7.5	60 ft. (N=9)
	Total	100.7		
Total Microtus/acre		276.7		

Conclusions from First Phase of the Study

The fire did not cause direct mortality of the voles. This agrees with Lawrence's findings on rodent survival in chaparral fires in the Sierra Nevada foot hills (1966). Most of the voles survived the heat and direct flames by taking refuge in burrows below ground level. Though there was abundant food present after the burn in the form of plant meristem and roots below the ground, all cover was eliminated above ground. The voles did not crowd into, nor significantly raise densities in the marginal grassy edges of the burn. There was no evidence of predators concentrating in the area after the burn, to utilize the exposed voles. It is concluded that in response to a decimated above-ground habitat, the vole populations moved out of the seven acre burn area into the very unfavorable surrounding area and were lost to the initial area occupied. The movement occurred in the two-three days immediately following the burn. The fire served to effectively eliminate all resident rodents from the burned area and this situation persisted until after emergence of the spring growth in late April.

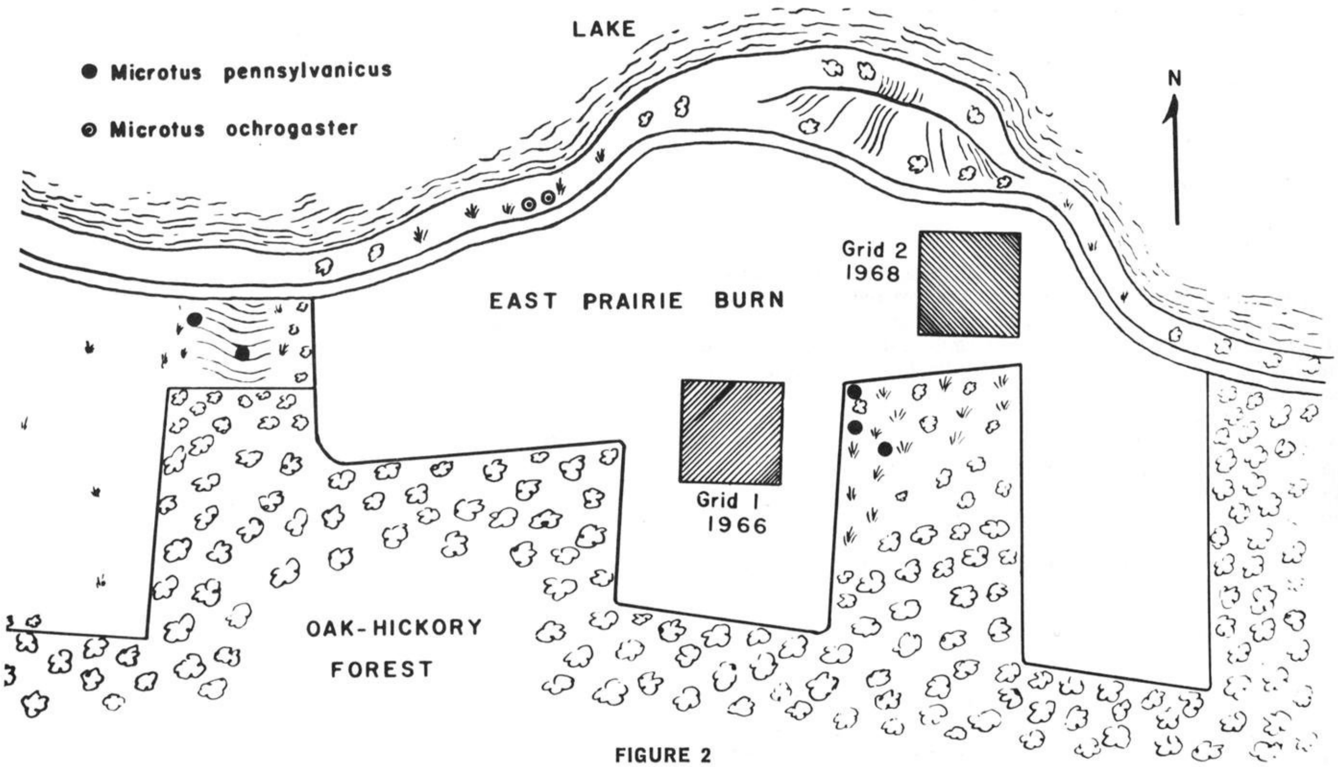

FIGURE 2

No burning or intensive trapping was carried on during 1967 but occasional live trapping indicated that mammal populations remained relatively low compared to the pre-fire densities of 1966.

Second Phase of the Study

The second phase of this study was to investigate the recovery rate from the effects of burning with respect to small mammal population densities. In the spring of 1968 a second study area (Grid 2) was set up in the East Prairie in prairie habitat very similar to Grid 1. In early April Grid 2 was burned along with certain other portions of the East Prairie. Grid 1, with about 1½ acres surrounding it, was left unburned. Intensive live-trapping continued on both grids through that summer following the burn. The results of this trapping are summarized in Table 2.

TABLE 2

Comparison of Mid-Summer Small Mammal Densities, 1968

		Density Per Acre *Unburned Prairie* (Grid 1)	*Burned Prairie* (Grid 2)
Microtus pennsylvanicus	♂	12.2 (37)	5.4 (48)
	♀	10.9 (31)	4.4 (34)
	Total	23.1	9.8
Blarina brevicauda	♂ + ♀	21.9 (31)	14.1
Zapus hudsonius	♂	3.3 (107)	5.1 (107)
	♀	1.6 (131)	5.1 (131)
	Total	4.9	10.2
Densities of *Zapus* that did not change grids	♂ + ♀	2.2	5.9

Note: (Number) indicates the *average distance between successive captures.*

The unburned prairie (Grid 1) had not been burned for two years plus three months. The burned prairie (Grid 2) had been very recently burned, three months before.

Results of the Second Phase of the Study

By mid-summer there were more than twice as many eastern meadow voles (*M. pennsylvanicus*) on the unburned Grid 1. This grid had a good accumulation of surface litter and vole trails could be found running through this litter. Short-tailed shrews (*Blarina brevicauda*) were also significantly higher in density on the unburned area. This species is quite fossorial and may well prefer abundant surface litter for protection and for forming surface and sub-surface runways. The prairie vole (*Microtus ochrogaster*) was apparently in such low numbers following the 1966 and 1968 burns that no captures of this species have been made in subsequent trappings. The reasons for this are unknown.

The eastern jumping mouse, *Zapus hudsonius,* was relatively abundant and was frequently recaptured enough times to provide some meaningful comparisons of densities for this species. It seemed to prefer the more recently burned parts of the prairie habitat. This area was remarkably free of litter even into late summer. The "understory" of such a grassland, during the first growing season after a burn, is very open and may provide a freedom of movement related to the specialized locomotion of *Zapus* with a resultant higher density in the burned area. It should be noted that the home range of *Zapus hudsonius* is considerably larger than the home range of the voles or shrews discussed, hence the grid size of 105 ft. may well be too small to determine accurate densities for this species. Supporting this was the fact that several of the jumping mice were moving back and forth between the two grids.

Two individuals of the western harvest mouse, *Reithrodontomys megalotis,* were captured several times during this trapping, and were moving back and forth freely between the two grids. It should also be mentioned that one individual of the house mouse, *Mus musculus,* was captured one time in the study area, but this species appears to be very rare in habitats away from buildings on the field station.

Just how long the effects of burning will influence small mammal population densities is currently being investigated by continuing to follow the grids under study.

It is becoming apparent from this initial investigation that fire in the tall-grass prairie at least initially depletes severely, certain environmental needs of voles and short-tailed shrews, and this effect may persist well into the growing season following the fire. Lack of surface litter is here suggested as a possible key factor influencing these reduced densities. Cook (1959) suggested that *Microtus californicus* needs at least one year's accumulation of mulch to afford this species adequate surface runway cover after a burn in the coastal hill grassland near Berkeley, California. Seed eating species of mice such as *Peromyscus* sp. and *Reithrodontomys,* re-invade quickly into western burn areas such as conifer slash, chaparral, and California coastal grassland (Tevis, 1956; Gashwiler, 1959; Cook, 1959). The seed eating species *Zapus hudsonius* seems to prefer the more recently burned tall-grass prairie but this may be related more to ease of movement through the more open understory of the grassland, than it is to increased food supply. The causative factors influencing post-fire rodent densities need still more investigation.

Acknowledgments

I wish to acknowledge the able assistance of Jerome Glickstein during the Spring of 1966 with the pre-burn trapping and analysis of the data.

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Session on: RESTORATION

Session Moderator: **PETER SCHRAMM** Department of Biology, Knox College

Vegetational Change on the Greene Prairie in Relation to Soil Characteristics

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Introduction

The purpose of this study was to determine the success of establishment of an artificial prairie, the H. C. Greene Prairie in the University of Wisconsin Arboretum, Madison, as it was influenced by the soil characteristics of the area and the locations of initial plantings.

The thirty-five acres which are now included in the prairie have been interpreted by Dr. Henry Greene as originally of the sand prairie-oak opening type (Greene 1949). The area is now bordered on the south by a railroad right-of-way which still supports some prairie species, and on the north by an open oak woods in the Arboretum. Before acquisition by the University in 1941 the entire prairie area was subjected to sporadic attempts at cultivation (Retzer 1951). The western half of the area was more intensively cultivated than the east, and plow ridges are still visible when a prairie fire removes the masking vegetation. But farming did not completely eliminate the prairie species from the land, and one corner was apparently relatively unaltered (Greene 1949).

Plans for establishment of a prairie were formulated in 1942 by the late Dr. Greene and were carried out almost entirely by him. Methods of establishment have been described by Greene and Curtis in a 1953 publication, and consisted of introduction of species by seed, seedlings grown in the greenhouse, transplantation of small blocks of prairie sod, or of mature prairie plants, and broadcasting mixtures of seed. Intensive revegetation was begun in 1945 and continued through 1952 (Greene 1949, 1966). Planting was begun at the east end and progressed westward. As a result, the density of planting decreased moderately to the westward. Occasional introductions have been made since the conclusion of the major project, but these add few individuals to the vegetational composition.

METHODS

The course of establishment of the prairie was recorded by a formal project of sampling the vegetation begun in 1952. At five-year intervals 1/10,000 A. quadrats were laid at 33⅓ ft. intervals along lines 100 ft. apart and perpendicular to a permanent baseline between easily recognized landmarks. Presence of each species in the 402 quadrats was recorded. Distributions of species were mapped and frequencies determined. This study employs the results of the 1952, 1961, and 1966 surveys, the latter conducted by the first author during July and August, 1966.

In order to compare the locations of species with some environmental characteristics, an analysis of some soil characteristics was conducted in September, October, and November of 1967. Locations of soil samples were at 50′ intervals along the same rows of quadrat locations. Per cent sand, silt and clay from 0-6 and 6-12 inch depths were determined by hand texturing, and the depth of A_1 was measured at every location. Additionally, 1/20 of the samples were selected randomly and collected for laboratory analysis of soil texture by the Bouyoucos hydrometer method (Day 1956). Correction factors for estimated silt, sand and clay values were determined by comparing estimated fractions with actual fractions determined in the lab for a variety of soil textures. Estimated percentages of sand, silt and clay for all field samples were corrected and placed in a soil texture class based on the soil textural triangle of the Soil Science Society of America. Areas of the resulting textural classes were delineated for comparison with other data.

The prairie continuum of Curtis (1955) was used to describe vegetational areas. Most of the 50 species used by Curtis indicating either wet, wet-mesic, mesic, dry-mesic or dry prairie were present in some area of the prairie. The Compositional Index (CI) of each quadrat was calculated, and wet, wet-mesic, mesic, dry-mesic and dry vegetation were mapped on the basis of quadrat CI. Stands for further analysis of individual species were designated using the vegetational areas thus obtained.

RESULTS AND DISCUSSIONS

Vegetational Change

Comparison of generalized vegetation maps of 1952 and 1966 shows that there have been recognizable changes in the extent and location of all segments of the prairie continuum. Figure 1 shows the vegetational areas as they were in 1952, the time of the first survey. A large disturbed area containing no indicator species, had shown little change toward establishment of prairie vegetation. The northern half was covered by species of dry prairie. The central area was a mixture of mesic and wet-mesic species, and the west end contained wet prairie species.

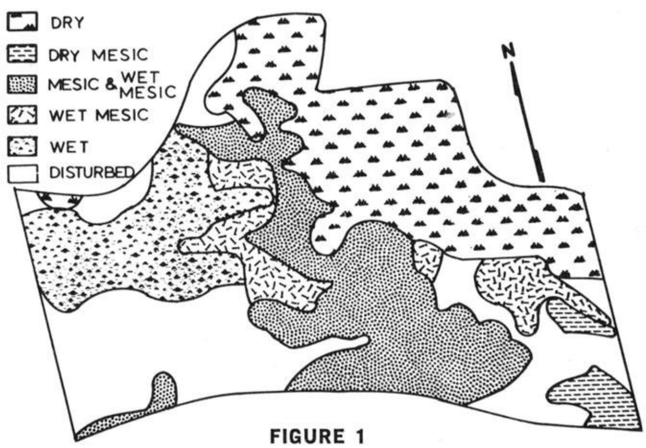

FIGURE 1

The pattern of prairie vegetation in 1952.

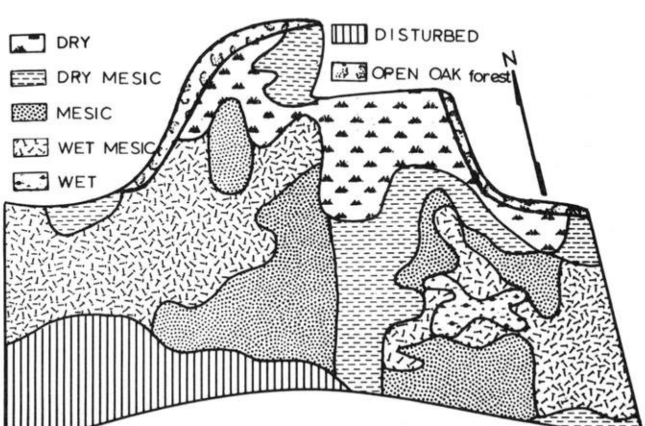

FIGURE 2

Patterns of prairie vegetation in 1966.

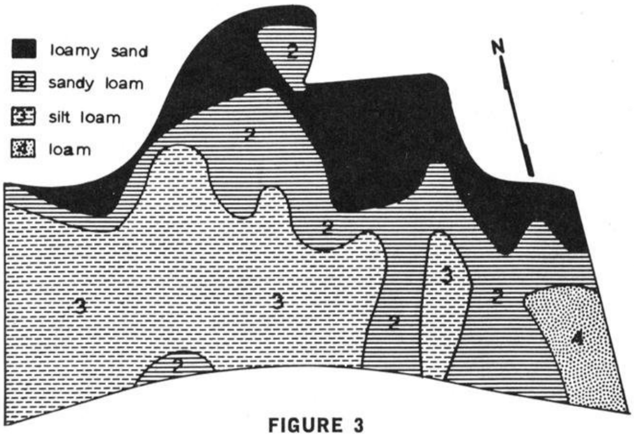

FIGURE 3

Soil textural classes of the prairie.

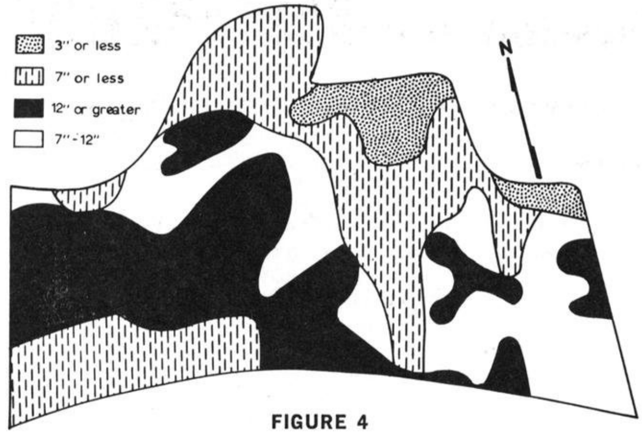

FIGURE 4

Classes of A_1 depth.

In Figure 2, 1966 vegetation is shown. The 1952 map masks scattered quadrats throughout each vegetational area which had no indicator species. The number of quadrats with no indicator species in 1966 was greatly reduced, and those rarely occurred within the vegetation areas designated. Number of indicator species per quadrat has also generally increased.

The former large areas of dry prairie at the north, and mesic wet-mesic prairie in the center have been converted to bands of dry, dry-mesic and mesic prairie vegetation. The successful establishment of wet-mesic prairie has also occurred. Of special notice are the extension of dry-mesic species to the northern boundary, absent in 1952, and the large area in the west, still relatively disturbed.

It is apparent that success of establishment of the prairie species was influenced in part by the location on which they were introduced. The original areas of dry, mesic, and wet vegetation on the prairie correspond in general with the areas in 1966. That species were located in suitable habitats is apparent.

The Soils

Evaluation of the soil texture reveals that the soils of the prairie are generally of two types in two distinct areas, as shown in Figure 3. Very high sand percentages characterize the loamy sand and sandy loam of the north and east regions of the prairie. Highly silty soils, silt loam and loam, constitute the remaining southwest part. Of special interest is the extension of sandy loam soils to the southern boundary of the prairie in parts of the eastern half and the small area of sandy loam surrounded by the larger area of loamy sand. Topography and drainage are such as to accentuate the environmental difference caused by the soil texture, as the sandy soils are higher in elevation than the silt soils, Drainage is generally from north to south and west to east.

Associating the vegetation with soil texture can be done by comparing the areas in which the various features occur. Comparison of Figures two and three shows that the dry prairie occurs almost entirely on the loamy sand soils. Dry-mesic vegetation corresponds largely with soils of sandy loam texture. The small area of sandy loam on the north edge is nearly identical with the location of dry-mesic vegetation there. Similarly the small patch of dry-mesic prairie at the west end is located on the loamy sand soil there, but not on the silt loam. Wet-mesic and wet prairie occur in greatest extent on the silt loam in the west end of the area, but also occur on the sandy loam in the east end. Both are lowland areas and have an adequate moisture supply.

Figure 4 indicates four categories of depth of organic matter incorporation. The general aspect is of increasing depth of organic matter incorporation from northeast to southwest within the prairie. Comparison of this figure with the vegetation shows that the dry prairie at the top of the hill has become established on areas with shallowest A_1. The deepest A_1 is largely in areas where wet and wet-mesic vegetation occur, but also includes some areas of mesic prairie. It is interesting to note that the area which was called disturbed also has a relatively shallow A_1 compared to the adjacent wet areas, probably because of the reduction of organic matter caused by cultivation.

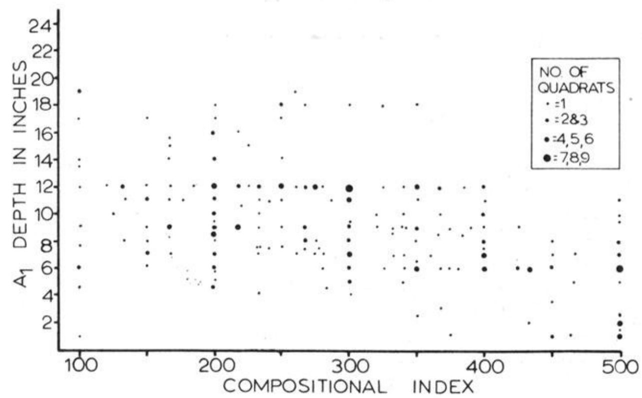

FIGURE 5

Depth of A_1 against Compositional Index of quadrats (1966).

In Figure 5 the depth of A_1 plotted against CI of the quadrats from the 1966 survey. The prairie CI scale goes from 100 at the wet end to 500 at the dry end. All moisture segments of the prairie continuum occur over widely varying depths of A_1, but a trend can be seen in that only CI's in the dry segment occur over a very shallow A_1 and only CI's in the wet segment occur over a very deep A_1. The intermediate range of depths supports vegetation with the whole range of CI values.

Species Changes

Marked changes have occurred in the frequency of many species over the period of fourteen years since the first survey. Of the 214 species encountered in the quadrats most prairie species have increased from two to sixteen times their 1952 frequencies. Weed species have decreased by nearly as much, with the two major exceptions of *Poa pratensis* and *P. compressa*.

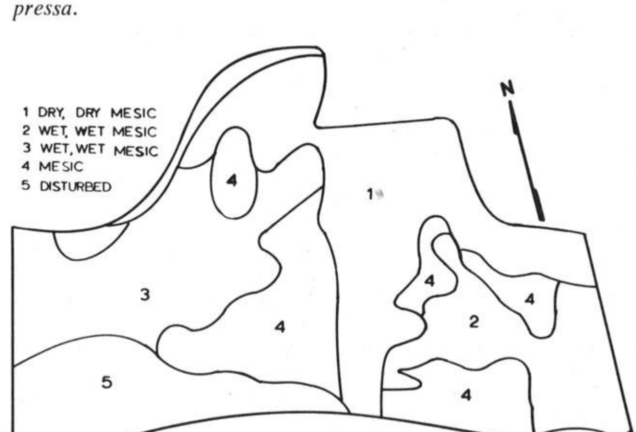

FIGURE 6

Location of stands used for analysis of species frequency changes.

In order to determine in which segments of the prairie individual species increased in frequency, the frequency of species within the vegetation areas was compared using the stands indicated in Figure 6. Changes in frequency for wet, mesic, dry and "disturbed" stands of several prairie species are shown in Figure 7. Species are arranged so that those making greatest changes in similar areas are together. Those species which show the greatest increase in the dry areas have increased relatively little in the other three areas. Species reaching their greatest increase in the mesic areas have shown somewhat smaller gains in the other areas. Wet increasers show very little increase in the mesic and dry areas. No particular group makes striking increases in the wet areas, but instead, a greater number of species have made relatively small increases in frequency. The disturbed stand shows small gains by several prairie species, and actual losses by two prairie species illustrated.

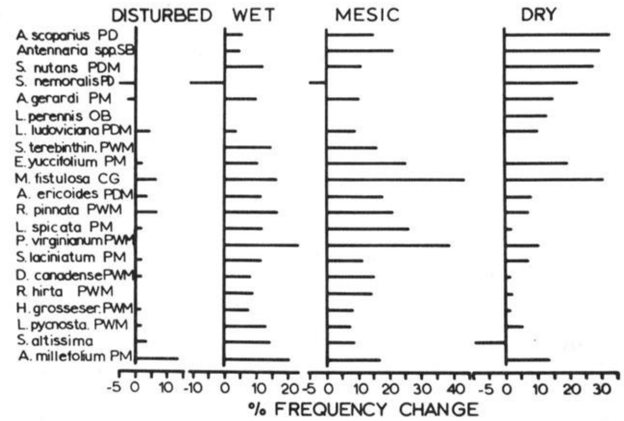

FIGURE 7

Per cent frequency change from 1952 to 1966 in four stands of some prairie species which have increased in frequency on the prairie as a whole. Modal communities (Curtis 1959): PD, dry prairie; PDM, dry-mesic prairie; PM, mesic prairie; PWM, wet mesic prairie; SB, sand barrens; OB, oak barrens; CG, cedar glades.

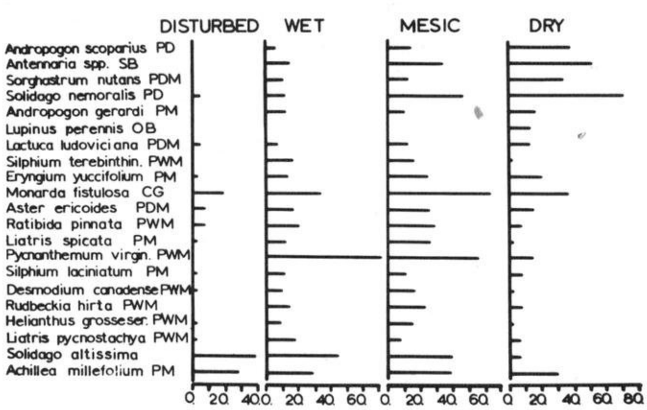

FIGURE 8

Per cent frequency in 1966 in four stands of some increasing prairie species.

Figure 8 shows the 1966 frequencies of the same species by stands. Generally the species were most frequent in the areas in which they increased most from 1952-1966.

Figure 9 shows weed species and prairie species making decreases in frequency over the study period. Most weed species which were important in the 1952 survey have been reduced in frequency in all areas. Frequency changes of the weeds are more uniform for all areas than changes of prairie species. More weed species increased in frequency in the disturbed area than in other areas. The greatest gain was made by *Agropyron repens.*

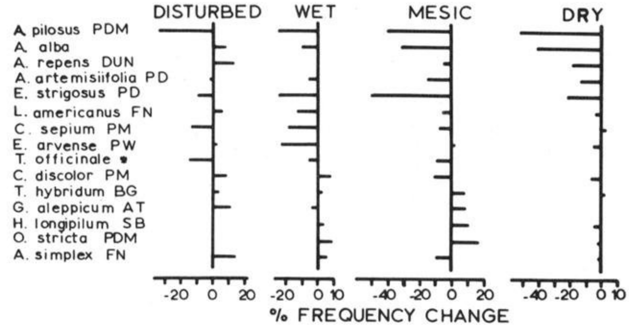

FIGURE 9

Per cent frequency change from 1952 to 1966 in four stands of some weed species and prairie species which have decreased in frequency on the prairie as a whole. Additional modal communities: AT, alder thicket; BG, bracken-grassland; DUN, lake dune; FN, fen; PW, wet prairie; *, species confined to a weed community or other disturbed area.

Several prairie species have shown decreases in frequency since 1952, as shown in Figure 9. For example, *Aster pilosus* has decreased from 25% to 50% in all areas, but the greatest decreases occurred in dry and mesic areas. *Cirsium discolor* and *Hieracium longipilum* showed differential responses among the several areas, decreasing in the wet and disturbed areas and remaining the same or increasing in the mesic and dry areas.

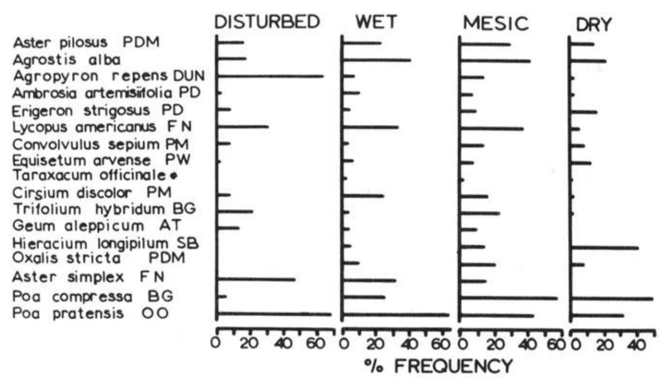

FIGURE 10

Per cent frequency in 1966 in four stands of some weeds and decreasing prairie species.

In Figure 10 the 1966 frequencies by stands are shown for the same species. In the areas in which the species showed greatest losses, they were least frequent in 1966.

Table 1 shows the average frequency change from 1952-1966 of the eight major weed species in the four stands studies, and the present average frequency of occurrence in the same areas. Of the four areas, the dry stand in 1966 had the lowest frequency and had the greatest average frequency decrease of weeds. The disturbed area had the highest 1966 frequency of weeds and had the least frequency decrease during the study period. The wet and mesic stands had intermediate values.

TABLE 1

Average frequency change (1952–1966) and average 1966 frequency of eight weed species, by stands.

	Disturbed	*Wet*	*Mesic*	*Dry*
Frequency Change (Average)	1.3%	−4.9%	−12.0%	−13.4%
Frequency 1966 (Average)	20.9%	10.3%	15.6%	7.3%

In summary then, during the survey years, the area occupied by the prairie vegetation increased. The vegetation of all segments of the moisture gradient shifted somewhat toward areas with soil charcteristics and drainage patterns indicating moisture conditions most similar to the native prairies in which they occur.

Analyses of changes in frequency of individual species shows that there are groups of species which have increased most in either dry, mesic, or wet stands and now have their greatest frequency in the same areas. A disturbed stand retains a large number of weed species and shows relatively slow progress toward reestablishment of prairie vegetation. Weed species have been reduced in frequency most in the dry stand and least in the disturbed stand.

While the species have shown considerable progress toward assorting on the basis of their ecological affinities, there are still differences between the Greene Prairie and natural prairies. Future changes which occur will result in a more precise placement of individual species to correspond with their occurrence in natural prairies.

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Summary of Morton Arboretum Prairie Restoration Work, 1963 to 1968

RAY SCHULENBERG

Morton Arboretum, Lisle, Illinois

The Morton Arboretum is located at Lisle, Illinois, in Du Page County, about 25 miles west of downtown Chicago. It was founded in 1922 by Mr. Joy Morton of the Morton Salt Company. The Arboretum now covers about 1,500 acres. Its major feature is an outdoor collection of living trees and shrubs, comprising most of the kinds that can survive the local climate. The Arboretum also contains remnants of native plant communities, such as marshes and groves. These are regularly used in the Arboretum's educational program, which encompasses the local wild flora and fauna as well as the cultivated plants. A small remnant of original prairie survived at the east end of the grounds until it was destroyed in 1964 by a utility company.

Meanwhile, however, the Arboretum had acquired some 25 acres of old farm land at the west boundary, incidental to the purchase of wooded home sites for the retiring Director and a Trustee. The Director, Mr. Clarence E. Godshalk, decided on prairie restoration to fit a plan of limited use and low maintenance for this remote parcel of land.

The goal was to replace the weedy Eurasian meadow vegetation then present with the community of prairie plants native to the immediate vicinity of the Arboretum. The job of re-establishing prairie was assigned to the present writer, then assistant propagator at the Arboretum. The precedent, inspiration, and basic procedural information for prairie restoration came to us from the University of Wisconsin Arboretum at Madison.

We decided at the outset not to buy seeds or plants from commercial sources and not to dig and transplant from remnant prairies. With negligible exceptions the plants in the Morton Arboretum project have been grown by us from seed we have collected from wild populations within 75 miles of Chicago. Local prairie remnants served as our models for species composition and proportion, and also served as our initial source of seed. Many of these local remnants have been destroyed by developments of one kind or another during the six years since we began our project. Where feasible we have obtained seed of each prairie species from several stations so as to preserve genes from as many as possible of the locally adapted populations.

Wisconsin had demonstrated that prairie plants can be established in bluegrass turf with management by fire. The acreage allocated for our project, however, was covered with coarse Eurasian forage plants and gross, aggressive weeds, instead of with bluegrass turf. We did not feel that we could succeed by introducing prairie seeds into such a hostile environment. We have made all our plantings in bare ground, plowed at least half a year before planting, and kept tilled up to planting time in an effort to reduce weed infestation.

The site included eroded hills, unfortunately north-facing for the most part; in many places all the topsoil had been eroded away, and the structure of much of the surface had been broken down by long agricultural abuse. Not realizing how difficult prairie re-establishment would prove to be, nor how much interest would develop in such projects, we did not engage in a systematic soil-testing program, nor did we set up quantitative trials to test various methods. We also failed to plant blocks of pure stands for seed. All of these measures would have facilitated the projects in the long run. Except for spreading barnyard manure on two fallow plots in autumn of 1967, we have not consciously modified the soils chemically. No irrigation has been available. In one small plot we excavated topsoil and deposited beach sand in an effort to provide a habitat for some of the Chicago-region sand-barren species. Otherwise we have merely tried on a "common-sense" basis to plant on each plot those species most likely to thrive there. Thus each planting has been an uncontrolled experiment in the adaptability of the soil to prairie vegetation, and in the feasibility of the restoration technique used. Although much can be learned from field observation of the results, no quantitative data have been produced.

Our work has been largely of a horticultural nature—intensive, on a small scale, with much hand labor. The first year, 1963, most of the planting was done with seedlings grown in the greenhouse from stratified seed; the seedlings were first transplanted into wood veneer plant bands in flats, and finally into the field at a spacing of about one plant per square foot. This technique enables one to control the initial distribution and proportion of the various prairie species. During the first years, hoping to achieve a naturalistic effect, we planted these banded seedlings in irregular strips, sometimes roughly following contour lines, and we staggered the plants deliberately to avoid straight rows. Since mechanical cultivation is not feasible where the plants are set so close together, and since herbicides cannot be used in the mixed community of prairie plants, hand weeding is necessary—hoeing, pulling, or cutting with knife or shears. Where plants are placed irregularly, such weeding is especially tedious.

In spite of the difficulties, we were encouraged by the success of this first planting. By autumn of the first year there was much flowering of certain composites and warm-season grasses; during the summer of the following year the new prairie was being used by Arboretum classes, and that fall it produced abundant seed, which was used in continuing the project.

Starting in May of the first year we also tried sowing seed directly in the field. Since the Arboretum does not own a drill that can sow prairie seeds, the procedure is to broadcast by hand the mixed, stratified seed on tilled ground, rake it, and trample or roll it in. This method calls for even more tedious weeding, but gives a smoother, more natural-looking result. One small plot for trial was seeded in 1964 with oats as a nurse crop to help control weeds; the advantage was not conclusive.

Three plots have over the years been seeded in the *fall*. For fall seeding we do not bother to clean the seed, but rather trample the coarse mixture of inflorescences with other plant parts on a drop-cloth, scatter it on tilled soil, and rake it lightly. Unfortunately prairie seedlings do not emerge until the next spring, and they are likely to be overwhelmed by weeds while still too small to compete. One plot was lost to weeds, but the other two, well weeded the first spring and summer, gave good results, though lacking early-blooming species.

Most of our planting, however, has been by spring seeding and by the transplant of banded seedlings from the greenhouse. Starting in 1966 we gave up the idea of randomized placement of bands, and started transplanting them in straight rows, using a specially designed planting board. The board provides a comfortable working surface for two men plus flats of seedlings, and its underside meanwhile marks the locations for planting the next 20 bands. Rows are kept straight by use of a taut cord. This planting board speeds up the transplanting operation greatly over previous methods, and the resulting plantings are far easier to weed than those with a randomized pattern. The artificial pattern is quite obvious the first year or two, and the unnaturalness of this plant community may be discernible for decades. Theoretically one could blend contiguous plantings smoothly by controlling the species composition, but we do not feel that the extra time demanded by this degree of perfectionism would be justified. An aerial view shows clearly the results of the various experimental planting techniques, but to an observer on the ground the plots blend fairly well.

After the first idealistic years, we have been content if any planting results in an association of even a few prairie species and is able to maintain itself in a relatively weed-free condition. The usual sequence is that a plot must be hand-weeded three times during its first growing season, and at least once the next spring; by the following spring the mass of plant material is usually dense enough to sustain fire. From that point on, the only maintenance necessary is by fire.

We try to burn between March 20 and April 10. This late burning preserves cover for soil and water conservation and wildlife cover as long as possible; also, this late date best achieves the main purpose of the fire—weed control. And fire at this time is still not so late as to injure most prairie plants. We use only matches, no torches or supplementary fuel. A sizeable portion of the restored prairie is left unburned every year—a different section each year—to provide habitat for birds, mammals, and especially insects.

Except for the present writer, the restoration work has largely been done by students during their summer vacations. We have had excellent help from this source. Arboretum personnel and machinery help with soil preparation and the maintenance of peripheral areas. Unfortunately, the most effective time for both planting and weeding is spring, and we have, during these six years, suffered a chronic help shortage from mid-April through mid-June. We hope to correct this situation next spring by a realistic recruitment program.

Our efforts so far have resulted in the establishment of some 120 prairie plant species covering altogether about six acres of land. Our most conspicuous failure is the shortage of spring-blooming flowers, such as lousewort, Indian paintbrush, puccoon, and yellow stargrass. Seeds of these species mature in midsummer, when there is no time to collect or process them; also, most of these plants are low-growing, so that their fruits are hard to find among the tall vegetation of midsummer.

There is usually abundant flowering in our plots from mid-June into October, and Arboretum visitors often ask to see the restored prairie during this time. Problems of privacy and traffic flow have up to now restricted the public's access to the restoration plots, but plans are underway to make the area more accessible. At present a good view is available from Leask Lane, our west boundary, where a sign reading "The Morton Arboretum Prairie Restoration Project" has been set up for the information of passing motorists.

Prairie Establishment at the Michigan Botanical Gardens

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Although better known for its lakes, bogs, and forests, Michigan also contains both wet and dry prairie elements. This was first pointed out by Gleason (1917) who described a wet prairie region in the southeastern part of the state, and Veatch (1927) who mapped the dry prairies in Southwestern Michigan. The latter areas were later shown in Transeau's map of the prairie peninsula (Transeau, 1935). More recently, Hauser (R. S. Hauser, unpublished material) has carried out an ecological analysis of certain of the dry prairies and Brewer (1965) has described the somewhat rare phenomenon of a wet prairie in Southwestern Michigan. So far over 140 native species characteristic of prairies have been reported in the state. Nevertheless, the areas comprising fairly pure prairie flora today are limited chiefly to railroad right-of-ways, neglected cemeteries, and on certain islands in St. Clair Lake northeast of Detroit (cf. Hayes, 1964). Thus due to man's disturbance, in Michigan, as elsewhere, the prairie community has nearly disappeared. The question dealt with here is whether a community closely resembling a native prairie can be recreated by man in a limited number of years.

At The University of Michigan Botanical Gardens, located in Southeastern Michigan near Ann Arbor, an attempt to establish such a prairie community is underway with the hope of providing researchers and students an outdoor ecological laboratory for grasslands investigation, and the public a small living museum of the region's native plants. This paper summarizes the results of the prairie establishment project from the date of its initiation, fall, 1967, to late summer, 1968.

SITE SELECTION

The eight acre site selected for establishment of the prairie had been a bluegrass meadow for several years, and before this, a corn field. At the time this experiment began, *Poa compressa* dominated the upper, drier parts, while *Poa pratensis* together with *Agrostis alba* dominated the lower, wetter and poorly drained areas. The site had not been mowed for a year and thus contained a heavy crop of weed seeds including *Daucus carota, Plantago lanceolata, P. rugelii, Rumex crispus,* and *Cirsium vulgare*. In addition to being a research and experimental center and readily accessible by foot or car, the area has certain other advantages: it presents a degree of topographic diversity with 0-12% slope, and most of the soil of the area, classified as Fox Sandy loam, a type characteristic of oak openings (Veatch *et al*, 1930) is well-drained. A few small areas, underlain by clay lenses, have local impeded drainage. With this amount of inherent variation in the topography and soil of the site, it is hoped that hydric, mesic and xeric plants can be successfully introduced and maintained.

The native vegetation which surrounds the site on three sides is a second-growth oak forest on the upland, and marsh and fen on the lowland. Thus the site also provides an opportunity to obtain an aesthetic blending of vegetation types in a setting largely shielded from weedy disturbed areas.

METHODS

A small experimental area, 100 x 150 feet, along with a fire break around the area, was plowed up in late fall, 1967. The remaining area was burned the following April with the idea of setting back the vigorous growth of the bluegrass. Since the area was still somewhat moist, it was difficult to produce a fire hot enough to be very effective against weeds. It was decided, therefore, to till this area often during the following summer in an attempt to reduce the existing weed population.

Two basic methods of establishment were tried in the experimental area: (1) juvenile and mature transplanting and (2) broadcasting seed (Fig. 1). Local seed collections for

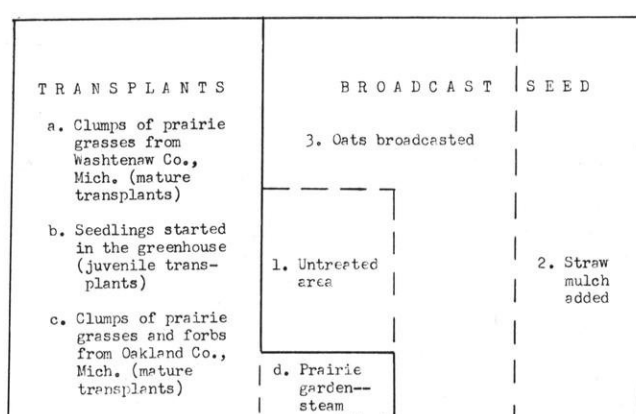

FIGURE 1

Experimental plot design for investigating methods of prairie species establishment.

broadcasting had been made during the previous fall. These, along with small quantities donated by the Morton Arboretum, Lisle, Illinois, had been stratified over the winter in moist sand at 34° F. In May approximately one half of the seeds were taken out of cold storage and planted in two inch peat "Jiffy-pots," 12-20 seeds per pot. Most of the thirty prairie species planted germinated within a week, although there was a wide variation in the percentage of germination. Only a few species, such as *Verbena stricta* and *Gentiana andrewsii* failed to germinate. Approximately 750 jiffy pots were transplanted directly into the previously designated area in early June. Clumps of prairie grasses with 8-10 inches of roots, obtained from nearby railroad right-of-ways, were also planted in the transplant area during May and early June.

A small area near the major transplant area was designated as a prairie garden to serve as a living herbarium of prairie plants with each plant labeled in an orderly arrangement. This area (20 x 30 ft.) was steam sterilized, as is commonly done with the cinders in greenhouse benches, by sending pipes through the soil. After the soil was sterilized, specimen samples in "Jiffypots" were transplanted into this area.

After broadcasting the stratified prairie seed by hand and raking it in, the broadcast area was divided into three sections: The first area was given no additional treatment; an oat straw mulch, ½ to 1½ inches deep was applied to a second area; and in the third area, oats were sown at a rate of 3 lbs./acre with a small broadcast seeder. The latter treatments were given with the intention of preventing weeds from taking over by either (1) shading their seedlings with straw or (2) overtopping them by sowing oats, a fast-growing annual crop.

RESULTS AND DISCUSSION

Transplant Area: Many weeds soon showed up in the transplant area, the most aggressive species were *Chenopodium album, Agropyron repens, Abutilon theophrasti, Polygonum aviculare, Dature stramonium, Plantago lanceolata,* and later on in the summer, *Eragrostis cilianensis, Digitaria sanguinalis,* and *Portulaca oleracea*. The weeds were kept under control during the summer, however, with hand weedings at four different times, and the transplants became well established. The quantity of water they received was a problem—not the lack of it, for the area was provided with overhead sprinklers, but rather by the unusual overabundance of rain resulting in flooding. The severe July rains washed out approximately 15% of the seedlings. All of the mature clumps of prairie grasses obtained from local railroad right-of-ways suffered no damage, however, and by early August these clumps were coming into bloom.

Steam sterilization, although initially a time consuming process (one half day for an area 20 x 30 ft.) proved to be an effective means of weed prevention for a small area. Only one wedding was needed to keep the steam sterilized plot relatively weed free.

Seeded Area

The broadcast seed area received no weeding except for two high mowings of both weeds and oats. No prairie seedlings were found in the three sections of the broadcast seeded area at any time throughout the summer. The original bluegrass meadow community with much *Potentilla recta* and *P. intermedia* made an almost complete return, although undoubtedly with some compositional change. The meadow weed species were able to germinate under the straw mulch, except where it was too thick to allow germination of any species. Furthermore the straw itself, since it contained dock seeds, served as an additional weed source. In the third section, only a good stand of oats was obtained, probably due to the density at which the oats were planted. By late August, after the second mowing, a blue grass community very similar to the one under the straw mulch and untreated area, had reappeared.

The results from the broadcast seed area vividly point out the aggressiveness of Eurasion meadow plants. However, the experiments in the broadcast seed area were not done on a very favorable basis: the straw mulch was not wired down (although it did stay mostly in place for at least a month); only a few pounds of prairie seed were available for broadcast seeding; and the area had only been plowed once. Thus, although broadcast seeding has not yet proved successful, we are planning to try this method again on the section which was tilled all summer using a heavy concentration of prairie grass seed with a known germination rate. Both spring and fall plantings are being considered. In addition, because transplanting turned out so successfully, a mass transplanting effort is being planned for next spring which will include participation by the public. Hopefully, sufficient area can be covered with transplants so that weeds can be controlled by spring burning rather than by hand weeding.

Although forty-four prairie species have become established at The University of Michigan Botanical Gardens site (Table 1), much is left to be found out about prairie establishment in Southeastern Michigan. It is expected that through broadcasting and transplanting techniques, and with the aid of spring burnings, in a few years the site will be transformed into one resembling a prairie.

TABLE 1

Prairie plants established at Michigan Botanical Gardens, 1968.

Amorpha canescens Pursh.	*L. spicata* (L.) Willd.
Andropogon gerardi Vitm.	*Lithospermum canescens* Lehm.
A. scoparius Michx.	*Lupinus perennis* L.
Anemone canadensis L.	*Monarda fistulosa* L.
A. cylindrica Gray.	*Panicum virgatum* L.
Asclepias sullivantii Engelm.	*Petalostemum purpureum* (Vent.) Rydb.
A. tuberosa L.	*Phlox pilosa* L.
Aster ericoides L.	*Potentilla arguta* Pursh.
A. laevis L.	*Pycnanthemum virginianum* (L.) D.J.
A. novae-angliae L.	*Ratibida pinnata* (Vent.) Barnh.
A. patens Ait.	*Silphium integrifolium* Michx.
Besseya bullii (Eat.) Rydb.	*S. terebinthinaceum* Jacq.
Bouteloua curtipendula (Michx.) Torr.	*Sisyrinchium albidum* Raf.
Cassia fasiculata Michx.	*Solidago graminifolia* (L.) Salisb.
Desmodium canadense (L.) DC.	*S. ohioensis* Riddell.
Echinacea pallida Nutt.	*S. rigida* L.
Elymus canadensis L.	*Sorghastrum nutans* (L.) Nash.
Equisetum laevigatum A. Br.	*Spartina pectinata* Trin.
Eryngium yuccifolium Michx.	*Veronicastrum virginicum* (L.) Farw.
Geum triflorum Pursh.	*Verbena stricta* Vent.
Lespedeza capitata Michx.	
Liatris aspera Michx.	
L. cylindracea Michx.	

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I would like to express my appreciation to fellow botany graduate students at The University of Michigan and to the Botanical Gardens staff for their assistance, both intellectual and physical, in carrying out this project. I owe special thanks to the Director of the Michigan Botanical Gardens, Dr. W. H. Wagner, for his encouragement to try such an experiment and to Mrs. Thomas Taylor and Mr. James Bennett for their many hours of work and valuable suggestions they have given.

Establishment of Prairie Species in Iowa

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Successful plantings of the tall grasses: big bluestem (*Andropogon gerardi*), switch grass (*Panicum virgatum*), Indian grass (*Sorghastrum nutans*), little bluestem (*Andropogon scoparius*), and Canada wild rye (*Elymus canadensis*), were made by Ada Hayden and John Aikman, Iowa State University, about 1950. Several dozen acres of this grassland still persist in Ledges State Park in central Iowa despite the tendency for encroachment of woody plants. Combinations of tall grass species and legumes were estabilshed in highway rights of way by Aikman and his students over the years (Kulfinski, 1957; McDill, 1961). But these efforts did not necessarily get us into the business of establishment of prairie species. Instead it grew out of attempts to investigate the natural dynamics of prairie vegetation, particularly in recovery after fire. Problems of identification of vegetative shoots and prairie seedlings following fire frustrated this effort and shifted our interests into following the germination and early establishment of prairie species (Christiansen and Landers, 1966). Now we are back to the study of fire in the prairie after several years of watching prairie species emerge from seed (Figure 1).

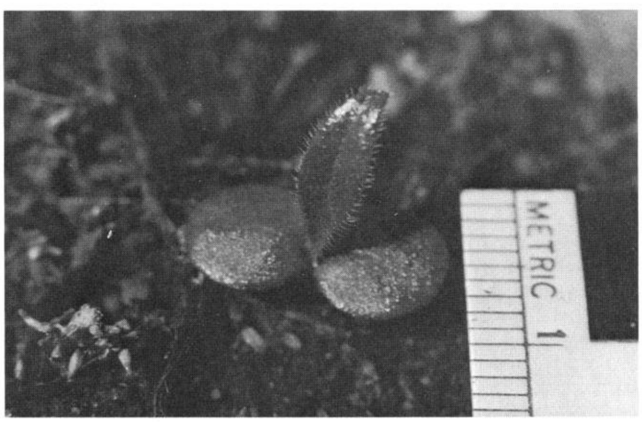

FIGURE 1

Seedling of purple coneflower (Echinacea pallida) **in first-leaf stage.**

From 1965 on, seeds of 65 prairie species were stratified and planted in Webster silty clay loam soil, a typical mesic prairie soil under cultivation in central Iowa. Various levels of competition were employed. Plots kept weed-free the first year resulted in the highest level of establishment with over half of the species flowering the second year. Where wheat was used as a cover crop, establishment was lower than in plots where annual weeds, mainly foxtails (*Setaria lutescens* and *S. viridis*) were allowed to remain as the only plant cover. By the end of the 4th growing season all species had flowered in the plots kept weed-free the first year. All had flowered in the wheat and weed competition plots except the compass plant (*Silphium laciniatum*) (Figure 2). By the end of the 4th growing season the plots looked rather free of weedy species because of the natural spread of such species as Canada wild rye (*Elymus canadensis*) and yellow coneflower (*Ratibida pinnata*) in between the rows and blocks of the original planting. Other vigorous competitors under these conditions were purple coneflower (*Echinacea pallida*), perennial sunflower (*Helianthus grosseserratus* and H. *laetiflorus*), oxeye (*Heliopsis helianthoides*) and goldenrod (*Solidago rigida*).

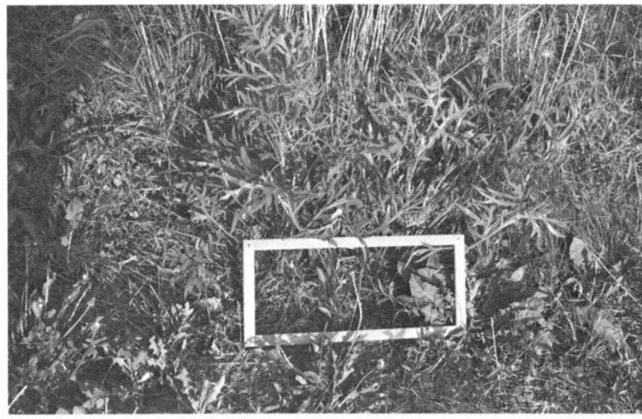

FIGURE 2

Compass plant (Silphium laciniatum) **framed by 20 by 50 cm quadrat in prairie establishment plots in June of the 4th growing season. Dandelions in the foreground are established outside the plot.**

The transplanting of prairie species by means of sod transplants 25 cm in diameter and 10-20 cm in depth was successful for 42 species during early spring. Fall transplanting has not been adequately tested, but we predict that it should be just as successful as early spring transplants if moisture is adequate. Sod transplants placed in formerly cultivated Webster silty clay loam soil were highly successful in competition with weedy species. Those placed in similar soil but in vigorous smooth brome (*Bromus inermis*) cover were generally unsuccessful. We feel that transplanting into established smooth brome is not advisable; however, our plots were inadvertantly mowed during the first growing season, an event which probably contributed to the low vigor of the prairie species as much as the competition from smooth brome.

Seedlings grown in the greenhouse six months were transplanted into Kentucky bluegrass (*Poa pratensis*) sod. Of 16 species, 15 were present and 7 were flowering after two years. Bluegrass sod appears to be less restrictive than smooth brome to the establishment of transplanted materials, but in either cover, it is unrealistic to expect very vigorous prairie species the first two years.

The best establishment after one growing season appears to be in deep loess material on slopes adjacent to Interstate Highway 80 in western Iowa. Survival of individual transplants approached 100% for several thousand seedlings of 17 species except where vigorous growth of various clover (*Trifolium*) species grew over the small seedlings (Figure 3). Establishment by seedling transplant in central Iowa under more severe conditions of soil and moisture resulted in survival of only one species, perennial sunflower (*Helianthus grosseserratus*), out of eight attempted.

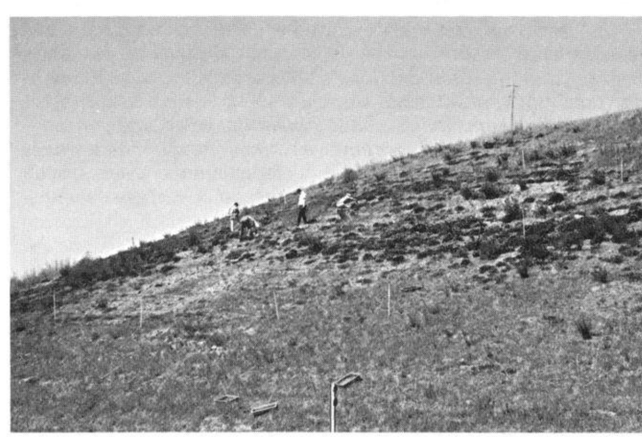

FIGURE 3

Prairie species planted on a southeast facing slope of Loveland Overlook, Interstate Highway 80, western Iowa. Dark material consists of several clover species which became vigorous competition with prairie seedlings.

From our experience we believe that most species can be transplanted or seeded directly into suitable soil if weedy species are controlled during the first year. Many species are able to compete with the annual weeds outright, replacing or restricting them after several growing seasons, but few are able to do well against established perennials, such as bluegrass or smooth brome.

Studies were begun in 1966 with support from the Iowa State Highway Commission on mixtures of herbaceous species useful on highway rights of way. Grass mixtures were seeded in June 1966 on 1/10 acre plots with one of the mixtures receiving several hundred seeds of prairie forbs in addition to the grasses. The seed bed was rototilled prior to seeding and drug with a toothless harrow afterwards. Mowing or spraying was not allowed, and at the end of the third growing season the perennial grasses were well established and in control of the site, and goldenrod (*Solidago rigida*) yellow coneflower (*Ratibida pinnata*) and blackeyed Susan (*Rudbeckia hirta*) were flowering in addition to the grasses. No maintenance was required on this area after planting, and at the end of three growing seasons, the only species of any consequence besides the planted perenniels were the white and yellow sweetclovers (*Melilotus*). This type of cover is what taxpayers should be clammering for.

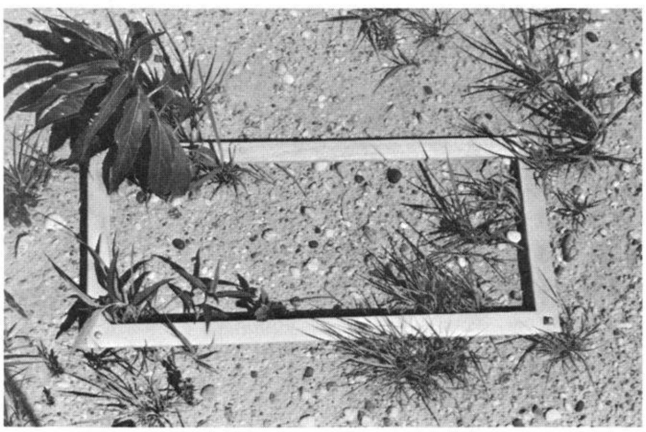

FIGURE 4

A mixture of tall prairie species on a severe subsoil along Interstate Highway 35, Story City, Iowa, framed by 20 by 50 cm quadrat. A perennial sunflower (Helianthus grosseserratus**) is obvious in the upper left corner and the grasses are mostly little bluestem (**Andropogon scoparius**). Planted June 13, 1968, photographed Sept. 3, 1968.**

Establishment plots of other grass species were attempted in June, 1968, on borrow areas adjacent to interstate rest areas in central Iowa (Figure 4). Soil conditions were chosen to represent a range from an extreme of unweathered glacial till to high quality agricultural soil. Severe erosion resulted in the loss of one series of plots; however on the most extreme site substantial establishment occurred for several species including side-oats gramma (*Bouteloua curtipendula*), bluegrama (*Bouteloua gracilis*), buffalo grass (*Buchloe dactyloides*), sand bluestem (*Andropogon hallii*), little bluestem (*Andropogon scoparius*), switchgrass (*Panicum virgatum*), and Indian grass (*Sorghastrum nutans*). Competition from annual grasses such as foxtail (*Setaria lutescens*) and crabgrass (*Digitaria ischaemum*) was more severe on the better soil sites.

Our experience suggests that the control of annual weedy species can be achieved by a mixture of prairie grasses and forbs by the end of the third growing season without mowing or spraying (Landers and Kowolski, 1968). If seed were more readily available there would be more extensive planting of prairie grasses and forbs along Iowa roadsides, rest areas and so called waste areas. Often there are large expanses of borrow and fill, associated with modern highway construction, which could be seeded to native prairies mixtures without expensive maintenance costs. Resistance to the presence of such species occurs because of the traditional viewpoint in Iowa that roadsides should look like mowed lawns, a condition under which most prairie species will not survive. We believe that this viewpoint is slowly changing, but it is a real challenge to convince the public that there is functional beauty in roadsides covered with a mixture of the original prairie species. We have enough ecological knowledge to begin, we need the political support to continue with the increased return of prairie species to our landscape.

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A Comparison of Two Transplanting Techniques in Prairie Restoration

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INTRODUCTION

A quantitative study of two transplanting techniques in prairie restoration was conducted. The two techniques employed were labeled as the Honeycomb Method and Peat Pot Method, representative as describing the two methods. These two techniques were compared quantitatively according to the survival of the transplants and in the height measurement of the individual seedlings. The experiment was conducted in the experimental field of Cornell College in Mt. Vernon, Iowa; this plot had been seeded with prairie grasses in the previous year. In April of 1968, the field was burned except for a small section in the northwest corner. By the middle of June, the field had become overgrown mainly by ragweed and guara. It was then mowed during the middle of June which left a six-inch cover crop.

Description of Experimental Site

Two sections of the field were selected for the experiment. Selection of the specific site was based primarily on slope gradient of the field; the site was level enough that water runoff would not be a significant factor in the comparisons. The unburned section in the northwest corner and a burned section were the two specific sites. In each section, eight linear plots of the seedlings were planted, four plots using the Honeycomb Method and the remaining four planted according to the Peat Pot Method. Within the four plots of each method, two plots were weeded. The seedlings, comprised of legumes, grasses, and a composite, were planted in a randomized manner in each plot with approximately a foot in between each seedling. Therefore, the design of the experiment consisted of sixteen plots employing the Honeycomb and Peat Pot Methods, and the two treatments in the comparison were burning and weeding. The main concern in the presentation is to compare the results of the two transplanting techniques. However, some findings obtained from the two treatments will be cited which are relevant to the transplanting techniques.

Methods and Materials

The seeds used in both methods were gathered from various sections throughout Iowa; some of the seeds were kept in dry storage while the others were stored out-of-doors during the winter months. In the Honeycomb Method seeds of a composite, three legume species, and three grass species were used. The composite was *Ratibida pinnata*, the three species of legumes were *Astragalus canadensis, Baptisia leucantha,* and

Desmodium canadense. The three grasses used were *Agropyron trachycaulum, Panicum virgatum,* and *Sporobolus asper.* After storage several seeds of each species were placed in moist, sterile soil in plastic bags and put into a refrigerator at 10 degrees centigrade. After three weeks of stratification, they were removed from the refrigerator. During this time flats were prepared consisting of individual paper cells into which the seeds were scattered according to species. The flats were then set out in the greenhouse for a month, and the seedlings were planted in the experimental site during the last week in June.

Ten species were planted using the Peat Pot Method. Again, the composite, *Ratibida pinnata,* was used and the following five species of legumes: *Amorpha canescens, Astragalus canadensis, Baptisia leucantha, Desmodium canadense,* and *Lespedeza capitata.* The four remaining species were grasses: *Agropyron trachycaulum, Andropogon gerardi, Sorghastrum nutans,* and *Stipa spartea.* After stratification in the refrigerator, the seeds were planted in perlite. Three weeks later each seedling was transplanted into a 2¼" peat pot and then left in the greenhouse for approximately two weeks. During the first week of July, the seedlings were planted in the site. During the second week of July, half of the plots of each method were weeded.

Results

Responses to the two transplanting techniques were measured first by taking a survival count of each individual seedling. This survival count was conducted during the second week of July. In Table I, the overall results clearly indicate that greater

TABLE 1

Total Survival Rate of Seedlings

Species	Honeycomb Method Planted	Honeycomb Method Surviving	%	Peat Pot Method Planted	Peat Pot Method Surviving	%
Ratibida pinnata	10	4	40.0	1	1	100.0
Amorpha canescens	-*	-	-	32	28	87.5
Astragalus canadensis	5	0	0	12	10	83.3
Baptisia leucantha	14	10	71.4	12	8	66.6
Desmodium canadense	25	7	28.0	29	26	89.6
Lespedeza capitata	-	-	-	29	28	96.5
Agropyron trachycaulum	15	2	13.3	103	66	64.1
Andropogon gerardi	-	-	-	24	23	95.8
Panicum virgatum	13	1	7.7	-	-	-
Sorghastrum nutans	-	-	-	14	12	85.5
Sporobolus asper	14	6	42.8	-	-	-
Stipa spartea	-	-	-	12	11	91.6
Totals	96	30	31.3	268	213	79.5

* No seedlings planted

numbers of seedlings survived in the Peat Pot Method. With the exception of *Baptisia leucantha,* the percent surviving in the Peat Pot Method is considerably greater than the per cent surviving in the Honeycomb Method; 79.5% of all species survived in the Peat Pot Method while only 31.3% were present in the Honeycomb Method. Breaking the total survival count down within the burned and unburned sections, the findings are identical: in the burned section per cent surviving in the Peat Pot Method was 76.8 and 25.0% in the Honeycomb Method; in the unburned section the results were respectively 82.1% and 37.5% for the two methods. It is to be noted that the survival rate of the unburned section was higher than the rate in the burned section.

A second sampling of response to the two transplanting techniques was taken by measuring the height of each surviving seedling. This measurement was taken a month after the first survival count. In each instance where a species could be compared between the two methods, the average height of the Peat Pot seedlings was greater than the average height of the Honeycomb seedlings. Again in dividing the site into the burned and unburned sections, the average heights of the peat pot seedlings were greater. However, looking at just the peat pot seedlings in the two sections, the average height was greater in the burned section. Yet, it was noted before that the survival count was greater in the unburned section.

TABLE 2

Total Height Measurement of Each Surviving Seedling. Average Height in Centimeters.

Species	Honeycomb Method Number Measured	Honeycomb Method Avg. Height	Peat Pot Method Number Measured	Peat Pot Method Avg. Height
Ratibida pinnata	4 (4)*	2.4	1 (1)	5.90
Amorpha canescens	-**	-	26 (28)	5.13
Astragalus canadensis	0 (0)	0	10 (10)	5.44
Baptisia leucantha	6 (10)	7.59	6 (8)	10.47
Desmodium canadense	7 (7)	4.85	26 (26)	17.58
Lespedeza capitata	-	-	27 (28)	8.97
Agropyron trachycaulum	1 (2)	0.8	44 (66)	8.35
Andropogon gerardi	-	-	22 (23)	22.23
Panicum virgatum	1 (1)	6.4	-	-
Sorghastrum nutans	-	-	12 (12)	13.89
Sporobolus asper	5 (6)	8.94	-	-
Stipa spartea	-	-	10 (11)	34.0
Totals	24 (30)		184 (213)	

* Numbers in parentheses indicate the number of seedlings surviving after the survival count
**No seedlings planted

In Table II it is interesting to note the difference between the number of seedlings surviving during the first count with the number surviving at the time of height measurement. In the Honeycomb Method the total number of seedlings surviving in the first sampling was thirty while a month later the number measured was twenty or 80% surviving; in the peat pot seedlings the number had been reduced from 213 to 184 or 86.4% surviving. The largest survival drop in the Honeycomb seedlings was *Baptisia leucantha* which was reduced from ten to six seedlings. *Agropyron trachycaulum* in the Peat Pot Method reduced considerably from sixty-six to forty-four. On the other hand, 64.1% of *Agropyron trachycaulum* survived in the Peat Pot Method while only 13.3% of this grass survived in the Honeycomb Method. However, it is difficult to compare this particular species between the two techniques because of the difference in the number planted by the two methods.

Discussion and Summary

From the results it is concluded that the Peat Pot Method is the better transplanting technique. A greater per cent of the seedlings survived in the Peat Pot Method, and of those surviving, the peat pot seedlings became better established in the environment. Even though the results show a considerable survival difference between the two transplanting techniques, one must take into consideration the environmental factors at the time of planting. Above average temperatures dominated the first week that the honeycomb seedlings were being planted, and this element probably has an important bearing on the survival rate of these seedlings. Furthermore, it is felt that of the two treatments used, burning and weeding, burning has played a more important role in the survival rate and growth of the seedlings. No substantial evidence can be concluded as to the effect of the weeding treatment; there were instances in which the average heights of the species varied sporadically within the plots themselves, and no noteworthy comparison can be made between the weeded and unweeded seedlings. It is felt that the weeding treatment is not relevant in the comparison of the two transplanting techniques.

Hill Prairie Restoration

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Relict short grass prairies dominate many of the south and southwest-facing slopes above major rivers in the middle west, usually on steep slopes above rather precipitous bluffs. For this reason, they have been called "hill" or "bluff" prairies. These beautiful biological gems dominate scenic vistas above particularly the Mississippi, Illinois, Missouri and Ohio Rivers, and contain a myriad of botanical and zoological species. In several midwestern states these form the bulk of the native prairie stands remaining. And so, although despite the fact that they are primarily xeric prairies, and dominated by xeric prairie species, they do possess an impressive list of prairie plants including many mesophytic species. These communities will undoubtedly become more important with each passing decade.

The Principia College Campus at Elsah, Illinois, some ten miles northwest of Alton, contains four miles of frontage on the Mississippi, and this stretch has a large number of these small, (seldom larger than one acre) distinct prairie areas. It is quite natural that much of our research effort at Principia has been directed to discovering more of the environment, soils and plant relationships that occur on these prairies.

In our area these prairies are dominated by little bluestem (*Andropogon scoparius*) and side oats grama (*Bouteloua curtipendula*), but contain a wide diversity of other grasses and forbs. A few publications are available which detail the species, composition and structure of these prairies, as well as the soil and other ecological features (Bland and Kilburn, 1966; Evers, 1955; Kilburn and Ford, 1963; Kilburn and Warren, 1963).

In the course of our studies, we have come to realize that these prairies are not static, that they are not climax prairie communities—at least in today's environment. In the 35 years that the college campus has been at Elsah, considerable change within these prairies and to the prairie—forest border here has occurred. This has become particularly noticeable in recent years. The bluff top, which was formerly a shrub-dominated ecotone, has become forested with young oak, hickory and ash saplings. Former trails have become overgrown; shrubs and trees in small ravines, cutting riverward, have rather obviously spread outward from this protected forest nucleus. In short, these hill prairies, when left ungrazed and unburned, have become smaller and smaller owing to the invasion of the forest elements from the outside.

At the same time, small tree seedlings and saplings in these small prairies, have grown, creating their own forest climate beneath, with the resultant elimination of the prairie grasses and forbs growing there.

When we at Principia had become convinced that we were "losing" our bluff prairies, we embarked on a program of stopping the spread of forest and even enlarging the prairie. This program consisted of three parts, or treatments, to three different areas of our bluffs as follows: first, transplanting clumps of prairie grass to a completely disturbed area; second, cutting down woody plants and poisoning the stumps in an area becoming overgrown with woody plants; and third, annual burning of an area where several small prairies were becoming overgrown.

Transplant Area

The transplant area is just below the college chapel in very disturbed and "weedy" ground, devoid of all native prairie species except big bluestem (*Andropogon gerardi*). It consists of about five acres formerly covered with black locust trees which formed an almost continuous cover and which, though often cut down, immediately resprouted in force. The slope was too steep to plow and seed, but we felt that scattered clumps of native prairie grasses would spread and crowd out the weedy *Bromus* and *Triodia flava* then dominating. First, the locust was recut, but this time the stumps were poisoned, and then grass clumps were planted with student labor. Clumps of both Indian grass (*Sorghastrum nutans*) and little bluestem (*Andropogon scoparius*) were selected, primarily because of their availability. The planting was done in both spring and fall of 1964 and 1965. Precise records were not kept but it was apparent that survival was quite successful at both times. Now, some three years later, and despite initial death of many of the transplant clumps, a patchy prairie grassland is present, and it appears that at some future time the area will be dominated by the bluestems and Indian grass. At the same time, we have been enriching the area with seeds collected by students of many prairie plants, and these have been scattered in the area. These, plus accidentally transplanted forbs whose roots happened to be gotten with the grass clumps, will provide more variation.

Cut and Poison Area

A major portion of the bluff area near the campus, extending almost half a mile, has been cleared and treated since the Spring of 1964. This area originally contained some of the least disturbed bluff prairies, but they were being badly invaded by such plants as *Cornus drummondii, Quercus velutina, Robinia pseudoacacia, Carya ovalis,* and others. Most of the invading species were small, with stems under 4" in diameter, and they were cut with hand tools, and the stumps were painted with 2,4-D and 2,4,5-T mixed with fuel oil. Most of the stumps were killed; the ones that resprouted were again cut and treated the following year.

One of the primary purposes of this work has been aesthetic. The area is readily accessible to the entire campus and very popular for scenic strolls. We have accordingly allowed certain trees and shrubs to remain in the prairie to enhance the view of the river below. At the same time, the net result of this effort has been to enlarge the existing prairies a great deal. Now we are finding little bluestem and other prairie species invading cleared areas, and it is clear that the prairie will quickly replace the forest here.

Often, however, the forest species do persist. For example, *Helianthus divaricatus*, the common woodland sunflower, often persists in the open prairies after removal of sheltering tree cover which allowed their invasion in the first place.

Burn Area

The prairies located in the bluff area just below the picnic grounds were among the most heavily overgrown and were selected as the site of a long term burning experiment study. The area immediately adjacent to this was a privately owned enclave within the campus, and this area had been burned periodically for some twenty years by the private owners. Consequently, their bluff prairies resembled prairie savannas, with scattered large black, white, chinkapin and post oaks occurring in the prairies. In the winter of 1963, we laid out eight permanent plots, took some vegetation measurements, and proceeded on an annual burning program. The burning was done in the early spring, after the snow was gone and the ground thawed, but while the soil was still very cold. As of now there have been four burns, the years 1965 and 1968 being too wet for burning.

The burns have favored the prairie plants, but far less than one would expect, and prairie expansion has been slow. Only where heavy grass cover surrounded a tree or shrub, would the fire be hot enough to kill the stem. Where the forest was well established, little or no damage occurred to the larger trees.

The prairie areas were originally becoming overgrown by many shrubs, especially, *Cercis canadensis, Cornus drummondii, Sassafras albidum, Rhus aromatica* and several tree seedlings of elm, oak and hickory. The burning first stimulated vigorous sprouting, but gradually both the number and size of the sprouts has declined and the prairie species have increased.

The result is that only moderate success accrued with our burning program in terms of converting the forest to grassland. Our feeling is that spring burning is far less influential than fall burning would be, but fire danger is too great to burn in the fall. As is evidenced with the contrast between the heavily forested campus area and the privately owned savanna area adjacent, turning the balance from mature forest to grassland is a slow process. Too many years had elapsed before the burning program was begun to enable the quick conversion to grassland. It is clear, however, that continued burning will gradually kill the woody plants and enlarge the prairie areas.

In comparing the burning and the clearing-poisoning techniques, there is no question as to the ease, permanence and low labor requirements of the clearing-poisoning approach in this area. Burning in this rugged terrain requires a large number of people for safe fire control, and the use of this approach is completely uneconomical. At the same time, a small crew working for only a short period can clear, poison and eliminate woody plants permanently, and this is the method we strongly advocate for situations similar to this.

Transplanting prairie plants is likewise quite tedious and although slow, it appears that our work will eventually be successful in establishing prairie plants in this disturbed area.

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Some Aspects of Establishing Prairie Species by Direct Seeding

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Introduction

This research, concerning the establishment of prairie species by direct seeding, was accomplished during the early phases of an attempt to establish an artificial prairie at the Boerner Botanical Gardens, Hales Corners, Wisconsin.[1]

From the inception of the project in the summer of 1965, the development has proceeded with its ultimate goal being the re-creation of the general appearance of a native Wisconsin prairie. It is well realized that it is a difficult task to re-create a true prairie, which in nature is the end result of lengthy and complex ecological succession and phyto-sociological relationships. Indeed, it may be impossible even to collect seed of all the vascular plant species necessary for a prairie. It was felt, however, that in view of the success of other artificial prairie establishments, notably that of the Curtis Prairie at the University of Wisconsin Arboretum, we would be able eventually to reach our limited goal (Greene and Curtis, 1950, 1953).

If an artificial prairie can be developed, it will, even though perhaps imperfect from a botanical and scientific standpoint, be an interesting and attractive addition to the landscape, and a valuable tool for the teaching of the ecological concepts of conservation. It will also serve as a demonstration area, seed source, and gene pool for native plants of potential landscape and horticultural use.

The artificial prairie will be an important addition to the Boerner Botanical Gardens, and knowledge gained during its establishment may be even more important. Aside from the botanical and ecological importance of prairie stands, the landscape possibilities of the prairie plants themselves are almost unlimited. For sheer beauty, the prairie species, collectively and individually, are unsurpassed. Many areas of park, parkway, and roadside, which now consist of weed vegetation or must be maintained by mowing, could conceivably be managed for prairie species establishment. If additional knowledge concerning artificial prairie establishment can be gained through the Boerner Botanical Gardens research, it may prove of great practical benefit to these future developments.

The idea of roadside management for prairie species is gaining in prominence, and the Milwaukee County Park System has set a precedent: since 1957 it has been official policy to refrain from mowing nonwooded areas which are not needed for formal picnic grounds. This policy alone has resulted in the incursion of some of the commoner native prairie species into park areas from which they were formerly excluded. If further practicable seeding and management techniques can be developed, these areas could begin the long road back to an approximation of native countryside.

The first actual step towards prairie establishment at the Boerner Botanical Gardens was taken in the fall of 1965, when the initial seeding was done. The area picked for the experimental prairie is in a portion of the Gardens which is not officially open to the public, and therefore does not receive much traffic. It is about four acres in size, and has soil types ranging from sandy loam to peat, and topography varying from creek bottom land to steep slope to level hilltop. The soil is predominantly a Miami Silt Loam, formed under forest vegetation on gravelly clay till of late Wisconsin age, and is considerably eroded on the slopes. The slope, which comprises much of the area, faces east.

It was thought that we might establish natural prairie moisture gradients, from wet to mesic to dry, because of the range of extant topography, soil types and moisture relationships. The area was formerly pasture and hayfield, and had been mowed for hay up until a few years ago. The grasses present were primarily bluegrass and quackgrass, but several clumps of *Andropogon gerardi* Vitm. were present in the low areas. Species of *Aster, Solidago, Ratibida, Asclepias, Penstemon, Fragaria, Antennaria, Sisyrinchium,* and *Helianthus* have been observed to be increasing since mowing was terminated, although no attempt has been made at vegetational studies in the original sod. The area has not been burned in recent times.

Twenty plots, totaling about one acre, were plowed, disked and seeded in the fall of 1965 (Figure 1), and another thirteen plots, totaling three-fourths acre, were similarly treated in the spring of 1966. The initial seedings included four grass species and eight forb species, seeded at the total rate of sixty bulk pounds per acre. Recommended seeding rates for the four grass species range from fifteen (U.S.D.A. Pub., 1948) to nineteen bulk pounds per acre (Wilson, unpublished paper)[2] using a Nisbet drill, under Western range conditions. To compensate for lack of special equipment, possibly more rigorous growing conditions, varying viability of the seed used, and varying amounts of chaff present, the grasses were seeded at a rate of thirty-five bulk pounds per acre (see Table IV). In addition, the forbs were seeded at a bulk rate of twenty-five pounds per acre. Seed was obtained from the University of Wisconsin Arboretum and a commercial range seed source in Polk, Nebraska, the Wilson Seed Company.

Since the initial seedings, many other prairie species have been transplanted into the general area. These have been obtained both as sod clumps from local native prairie remnants, and as specimens grown from seed obtained from various sources. These additions have not, however, been planted in the original seeded areas, but rather, between those plots.

The scope of the entire project includes not only the establishment of the prairie species themselves, but also extensive germination and propagation studies, including cold stratification and fire treatment experiments (see Table I), analyses of the numbers of pure seed per bulk pound when harvested (see Table II), herbarium collections from local native prairie remnants, and extensive seedling herbarium specimen mountings.

This paper covers in detail the methods and results of the fall 1965 seeding. The vegetational studies, to determine the success of that seeding, were done in late June of 1967, one full growing season and a full spring after planting. The study compares the suitability of the two seed sources for native grasses, the efficacy of various mulch types in seedling establishment, and investigates the performance of the grasses and forbs relative to their establishment on the various slope and drainage sites.

METHODS

The entire fall 1965 seeding project was planned during a series of conferences, held variously at the University of Wisconsin Arboretum at Madison, the University of Wiscon-Milwaukee, and the Boerner Botanical Gardens. Conferences were held during July, August, and October of 1965. Members of the Botanical Gardens staff met with Dr. David Archbald, University of Wisconsin Arboretum Director, and with Dr. Philip B. Whitford, Chairman, Department of Botany, University of Wisconsin-Milwaukee. Drs. Archbald and Whitford are largely responsible for the basic methods outlined here.

During these meetings it was agreed that it would be better to spot-plant plots throughout the proposed area, rather than to concentrate all efforts in one location. This would facilitate the comparison of edaphic variables, seed sources, and treatments by sampling discrete plots, yet allow distribution of test plots in the full range of edaphic conditions. The entire area will take some years to plant, because of limited seed availability. By scattering plots throughout the entire area, we will obtain more of the appearance of a prairie in a shorter time than by seeding a single larger section of the area. Such an arrangement might also encourage the plants established in the plots to encroach on the surrounding non-seeded areas, particularly after the plants mature and managed burning can take place (Curtis and Partch, 1948).

It was decided to plow, disk, and cultivate these plots to eliminate as much of the bluegrass, alfalfa, and quackgrass as

[1]The Boerner Botanical Gardens are located in Whitnall Park, Hales Corners, Wisconsin, and are a unit of the Milwaukee County Park System.

[2]Editor's note: Published in this symposium.

possible before seeding. After preparation of the seedbed, permanent metal stakes were driven into the four corners of each of the twenty plots.

A total of twenty-four possible combinations of variables were defined for the purposes of experimentation (see Table III). The topography of the site lent itself to the investigation of three slope and moisture variables: level, mesic hilltop (A); steep, dry slope (B); wet lowland (C). Four mulch variables were investigated: marsh hay (M); cultivated straw (S); hay from the Curtis Prairie of the University of Wisconsin Arboretum at Madison (A); no mulch (X). Two grass seed sources were compared: seed collected at the UW Arboretum (W); seed purchased from the Wilson Seed Company, Polk, Nebraska (N).

Three sub-plots per variable were established, for a total of seventy-two sub-plots. These sub-plots are not necessarily of the same size. The only requirement is that there be twenty-four for each main plot-type, and that each be at least two meters in width by five meters in length, which is the size of the grid used in the population analysis. The sub-plots are distributed at random throughout the twenty main plots. Six of the main plots are in slope-type A, seven in slope-type B, and seven in slope-type C.

Of the twenty main plots, ten were seeded with a mixture of UW grasses and forbs (see Table IV), and ten were seeded with a similar mixture of Nebraska grasses (of the same species as those obtained from the UW Arboretum) and UW Arboretum forbs. The amount of Nebraska seed added to Arboretum forbs was adjusted to compensate for percentages of seed to bulk weight slightly different from those of the Wisconsin grown grasses. This factor is undoubetdly a function of the different harvesting techniques employed.

The plots were seeded by hand because high percentages of chaff, and varying seed sizes, made mechanical sowing impractical, particularly since reasonably even distribution was necessary in order to obtain valid statistical data. The seed was thoroughly mixed with damp sand in order to facilitate sowing. The seed was sown, at a rate of sixty bulk pounds per acre (see Table IV), in late November of 1965. The various mulches were then applied and tied down with baling twine and spikes; twenty five bales of straw, twenty bales of marsh hay, and approximately one two and one-half ton truck load of loose UW Arboretum prairie hay were used. Approximately fifty man-hours were required to complete the mulching and tying. The mulch was applied at about the same thickness as it would be for general lawn grass seeding.

The data for each plot and sub-plot type was gathered during the summer of 1967, and is presented in Tables VA, VB, and VC. The mulch and seed type variables, excluding slope type, are summarized and totaled in Table VI. Each sub-plot type is outlined, with results for each comparison expressed in density per square meter. The data was collected by placing a ten square meter grid, two meters wide by five meters long, in each sub-plot, and counting all the individuals of the planted species present in a one-fourth square meter area of each square meter of the grid. The one-fourth meter square to be sampled in each square meter was randomly determined. The data for each variable were subjected to a standard test for ninety-five percent confidence interval for estimate of population size (Table VII), and their population densities were compared by The Five Percent Level of Satistical Significance Method to determine whether there were statistically valid differences in population density as a result of the seed source or the mulch treatments (see Table VIII).

RESULTS

All the populations sampled exhibit an estimate of populations which falls within the ninety-five percent confidence interval for estimate of population size (see Table VII). The entire sampling procedure is therefore statistically valid, and conclusions can be drawn from the data acquired (Snedecor, 1956).

During the summer of 1967, and while reviewing the data gathered, it became evident that the species were not as yet being selected as to major slope and drainage sites, since there were no observable differences in seedling survival which could be correlated with moisture conditions. However, this is a factor which may take some years to become evident, since the overall moisture conditions of the site probably do not vary greatly enough to materially affect germination and early survival of the species planted, although they may affect inter-specific competition later (Cottam and Wilson, 1966).

The remaining variables to be considered are seed sources and mulch types. The primary purpose of this research, then, is to compare commercial Nebraska range grass seed with native Wisconsin seed of the same species, and to compare the efficacy of four mulch variables. Statistically comparing the means of the populations (see Tables VIII and IX) reveals that the following populations have densities per square meter which are significantly different at the five percent level of statistical significance:

1. XW and XN (All Species), XW>XN.
2. XW and MN (All Species), XW>MN.
3. XN and MW (All Species), MW>XN.
4. XN and AW (All Species), AW>XN.
5. XN and SN (Grasses), SN>XN.
6. XN and SN (All Species), SN>XN.

In addition to the above differences, the populations XN and AN (Grasses), AN>XN, exhibited a probability factor of 1.95, only .01 less than the 1.96 factor denoting statistical difference at the five percent level.

DISCUSSION

A point by point analysis of the statistically different populations outlined above will allow an easier discussion of the primary factors being investigated, i.e., seed source and mulch type variables.

1. *XW and XN (All Species), XW>XN.* This comparison of unmulched Wisconsin grasses and forbs with a mixture of unmulched Nebraska grasses and Wisconsin forbs has no relevancy to the problems of mulch or seed types. There was no mulch comparison, since neither were mulched, and the comparison of the grasses revealed no significant statistical difference between them. The better performance of the Wisconsin forbs in the XW population is attributable to other factors, such as weed incursion, or microclimate, or other chance differences in the plot sites.

2. *XW and MN (All Species), XW>MN.* Here again, there was no significant statistical difference between the Nebraska and Wisconsin grass seedlings, so the comparison is between unmulched and mulched Wisconsin forbs. The greater density of unmulched forbs might indicate that mulching, at least with marsh hay, is detrimental to forb seedling establishment.

3. *XN and MW (All Species), MW>XN.* Again, there was no significant difference in the grass populations, therefore the only comparison is between mulched and unmulched Wisconsin forbs. The greater density of the mulched forbs might indicate that mulching with marsh hay is beneficial to forb seedling establishment.

4. *XN and AW (All Species), AW>XN.* Since there was no statistically significant difference between the grasses, the comparison is between Wisconsin forbs mulched with Arboretum prairie hay and unmulched Wisconsin forbs. The greater density of the mulched forbs could be attributable to either the additional forb seed presumably present in the Arboretum hay, or to the beneficial effects of mulching. Since a comparison of AW and AN populations, where two Wisconsin forb populations are mulched with Arboretum prairie hay, reveals no significant statistical difference, it must be assumed that the Aboretum prairie hay, acting as a mulch, might be beneficial to forb seedling establishment.

5. *XN and SN (Grasses), SN>XN.* The mulch variable, straw compared to no mulch, is the only factor compared here. A similar comparison of Wisconsin grasses, XW and SW, revealed no significant statistical difference. The straw mulch might be considered beneficial to Nebraska grass seedling establishment, yet of no benefit to Wisconsin grass seedling establishment. This might infer that the Nebraska grasses are less hardy, since they benefit from mulching.

6. *XN and SN (All Species), SN>XN.* When the forbs alone are compared (by subtracting the grass densities from the All Species densities) as to mulch type, there is still a much greater density of S population than X population. This might infer that the straw mulch was definitely beneficial to forb seedling establishment.

7. *XN and AN (Grasses), AN>XN, Probability Factor 195.* Although not meeting the five percent level of significance, it is close enough to warrant discussion. The greater density could be attributable to either the efficacy of the Arboretum prairie hay as a mulch, or to the possible addition of seeds to the population, or both. The comparison of populations XW and AW, however, reveal no statistically significant difference, therefore the presence of a statistically significant amount of grass seed in the Arboretum prairie hay is unlikely, and the increased density of AN>XN probably results from the beneficial effects of mulching. Since XW and AW comparisons were not significantly different, it can be inferred that the Wisconsin grasses did not benefit materially from mulching, and whereas the Nebraska seed did benefit, that the latter is less hardy.

Summary of Discussion

Of fourteen comparisons of marsh hay with the other mulch treatments, in one instance it was less beneficial, and in one instance more beneficial, to forb seedling development, than the other mulch treatments.

Of fourteen comparisons of straw with other mulching treatments, it twice proved more beneficial to forb seedling development than the other treatments.

Of fourteen comparisons of Arboretum hay with other mulching treatments, in one instance it proved more beneficial (as a mulch, presumably, not as a seed source) to Nebraska grass seedling establishment.

CONCLUSIONS

It can readily be concluded, from the above results, that commercial Nebraska range grass seed is comparable, in germination and initial adaptability, to native Wisconsin seed of the same species. The fact that a straw mulch proved beneficial to the Nebraska seed in one instance (SN>XN) is far outweighed by the fact that there was no significant statistical variation shown by the comparisons AN-XN or MN-XN, or between Nebraska and Wisconsin seed in any of the mulch treatments. Even if the comparison SN>XN is construed as Nebraska seed being slightly less adaptable than the Wisconsin grasses, it is certainly not a serious enough factor to discourage its use on a large scale.

It can also be concluded that mulching in general is of no great benefit to Nebraska grass seedling establishment, and of no significant statistical benefit to native Wisconsin grass seedling establishment. Mulches in general showed a net beneficial result towards forbs twice in fifty-six comparisons, or in 3.6 percent of the comparisons. This figure obviously does not warrant their general use in establishing the species of forbs investigated.

Fall mown prairie hay does not contain enough seed to create a statistically significant difference in seedling density when it is applied to an already heavily seeded area. This does not preclude its use as a seed source when other seeding is not done, however, since it is a generally accepted concept that fall prairie hay, laid on a prepared seed bed, will contain enough seed to produce some prairie species seedlings (Cottam and Wilson, 1966).

Despite the above conclusions concerning the relative inefficacy of mulches in the establishment of the species investigated, it should be noted that they will still prove invaluable in preventing erosion when seeding is done on very steep slopes, and would probably prove beneficial in conserving moisture under very dry conditions, or perhaps during late spring seeding.

All of these conclusions would be useless if the densities of the populations investigated were so low that they would result in no practical concentration of prairie species. Even the lowest All Species density recorded, however, for population XN, has a total density per square meter of 76.4. Even if possible misidentification of some seedlings is considered, it would still show a very useful concentration of prairie species.

It should not be concluded that since the experimental site exhibits a high overall average density of prairie seedlings that the area is now "prairie." Much depends upon survival conditions in the next few years, and upon the application of proper management techniques, such as burning, selective brush cutting, and periodic mowing for weed species. At the time of the vegetational study, most of the plots were densely populated with various non-prairie species, such as white, yellow, and red sweet clover, alfalfa, timothy, quackgrass, bluegrass, red top, wild carrot, etc. The prairie seedlings in many plots were existing under a canopy of larger weeds. These weeds will have to be controlled, or the prairie species may not survive in any quantity.

Summary of Conclusions

There is no practical initial survivability difference between native Wisconsin prairie grass seed and commercial Nebraska range seed of the species investigated. This fact should provide the basis for further long-range studies of the practicability of using Nebraska commercial range grass seed in re-establishing native prairies in Wisconsin. It should be noted that there may be differences in photoperiodicity and other physiological characteristics between the Nebraskan and native Wisconsin ecotypes, and further research will determine whether such differences might be of such magnitude as to preclude the use of the Nebraskan seed in Wisconsin.

Under conditions of fall seeding, unless steep slopes are involved, mulching with prairie hay, straw, or marsh hay has not proven appreciably beneficial to the establishment of the species investigated.

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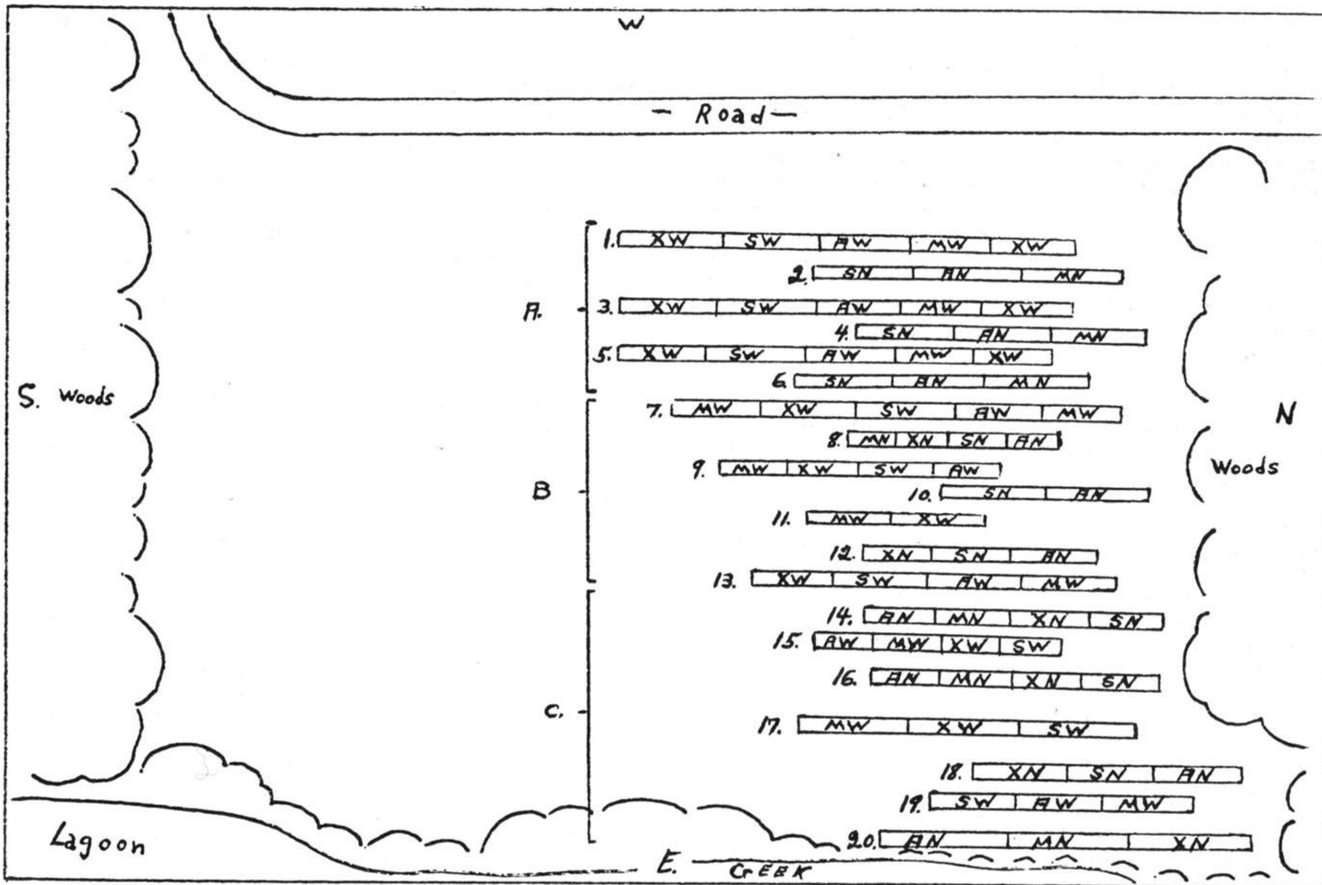


A. Highland. C. Lowland. M. Marsh Hay. S. Straw. N. Nebraska Seed.
B. Steep Hillside. X. No Mulch. A. Arboretum Prairie Hay. W. Wisconsin Seed.

FIGURE I

Map of Plots and Sub-Plots Seeded Fall 1965

TABLE I

The Effects of Various Treatments on the Germination of Some Prairie Species

Species*	I	II	III
Allium cernuum	0%	0%	1%
Amorpha canescens	0	0	0
Aster novae-angliae	0	2	0
Aster azureus	0	1	0
Dodecatheon media	0	0	0
Echinacea purpurea	0	14	1
Eryngium yuccifolium	0	0	0
Galium boreale	0	0	0
Gentiana andrewsii	0	0	0
Liatris pycnostachia	10	20	9
Lithospermum canescens	0	0	0
Monarda fistulosa	1	28	20
Muhlenbergia asperifolia	0	0	0
Panicum virgatum	0	0	0
Penstemon digitalis	0	0	6
Petalostemum purpureum	0	1	3
Ratibida pinnata	0	9	2
Silphium laciniatum	0	4	6
Silphium terebinthinaceum	0	12	32
Solidago speciosa	0	0	0
Sorghastrum nutans	2	0	18
Thalictrum dasycarpum	0	1	0

I=No stratification; an attempt at fall germination, 1966.

II=Normal outdoor stratification in damp sand, germination spring, 1967.

III=Stratification, and treatment with fire, in an approximation of the burning of an average amount of spring prairie litter, spring, 1967.

Note: further information concerning procedures, and additional data, may be obtained from the author, or from the Boerner Botanical Gardens.

*Nomenclature in this and following tables according to Gleason, 1952.

TABLE II

Numbers of Seed Per Bulk Pound

Species	Bulk Wt.	Seed Wt.	% Seed	Seeds/sample	Seeds/pound
Andropogon gerardi	0.2 gram	3 grains	50	208/gram	90,000
Andropogon scoparius	0.2 gram	3 grains	50	208/gram	90,000
Echinacea purpurea	1 gram	0.25 gram	25	113	200,000
Eryngium yuccifolium	2 gram	0.75 gram	37.5	451/gram	200,000
Helianthus occidentalis	2 gram	1 gram	50	800	360,000
Lespedeza capitata	2 gram	0.5 gram	25	280	250,000
Liatris sp.	1 gram	0.4 gram	40	296	330,000
Panicum virgatum	2 gram	1 gram	50	1000	450,000
Petalostemum purpureum	1 gram	0.25 gram	25	106	190,000
Silphium integrifolium	2 gram	0.45 gram	22	19	20,000
Silphium laciniatum	2 gram	0.8 gram	40	24	10,000
Sorghastrum nutans	0.2 gram	0.10 gram	50	81	360,000

The analysis is of seed collected in the fall of 1965, at the University of Wisconsin Arboretum, Madison, Wisconsin. (16 grains/gram, 453.6 grams/pound). Seed analyzed November, 1965. The figures are rounded off to the nearest 10,000.

TABLE III

Summary of Plot and Sub-Plot Types, Sizes, and Treatments

	PLOT SIZE	PLOT #	# SUB-PLOTS	SUB-PLOT TYPES	SEED WEIGHT	SEED SOURCE
A-HIGHLAND PLOTS	20X220 = 4400 sq. ft.	1.	5.	XMASX	6.0lbs.	W
	14X150 = 2100	2.	3.	MAS	3.0	N
	23X190 = 4370	3.	5.	XMASX	6.0	W
	12X150 = 1800	4.	3.	MAS	2.5	N
	19X220 = 4180	5.	5.	XMASX	6.0	W
	17X115 = 1955	6.	3.	MAS	3.0	N
	SUB-TOTALS	6	24		26.5	
B-STEEP HILLSIDE	21X175 = 3675	7.	5.	MASXM	5.5	W
	14X120 = 1680	8.	4.	ASXM	2.5	N
	13X110 = 1430	9.	4.	ASXM	1.5	W
	18X85 = 1530	10.	2.	AS	1.5	N
	17X70 = 1190	11.	2.	XM	1.5	W
	15X90 = 1350	12.	3.	ASX	1.5	N
	13X135 = 1755	13.	4.	MASX	2.5	W
	SUB-TOTALS	7	24		16.5	
C-LOWLAND PLOTS	14X200 = 2800	14.	4.	SXMA	4.0	N
	12X165 = 1980	15.	4.	SXMA	2.0	W
	12X190 = 2280	16.	4.	SXMA	3.0	N
	15X120 = 1800	17.	3.	SXM	2.0	W
	12X135 = 1620	18.	3.	ASX	2.5	N
	14X110 = 1540	19.	3.	MAS	2.0	W
	15X90 = 1350	20.	3.	XMA	1.5	N
	SUB-TOTALS	7	24		17.0	
	TOTAL 44785 = 1.03 Acres		72		60.0	

A. Highland B. Steep Hillside. C. Lowland. X. No Mulch. M. Marsh Hay. A. Arboretum Prairie Hay. S. Straw. W. Wisconsin Grasses. N. Nebraska Grasses.

TABLE IV

Seed Mixture

Andropogon gerardi (Big Bluestem)	5.00 lbs.	16.0%
Andropogon scoparius (Little Bluestem)	3.00	10.0
Echinacea purpurea (Purple Cone Flower)	1.00	3.0
Eryngium yuccifolium (Rattlesnake Master)	2.50	8.0
Helianthus occidentalis (Sunflower)	0.50	1.5
Lespedeza capitata (Bush Clover)	2.50	8.0
Panicum virgatum (Switchgrass)	5.00	16.0
Petalostemum purpureum (Purple Prairie Clover)	1.25	4.0
Silphium integrifolium and *terebinthinaceum*	5.25	16.5
Silphium laciniatum (Compass Plant)	0.50	1.5
Sorghastrum nutans (Indiangrass)	5.00	16.0
	31.50	99.5

This mixture was used to seed the Wisconsin plots. An identical mixture, using Wisconsin forbs and Nebraska grasses, was used to seed the Nebraska plots. Seeding rate = 60 pounds per acre.

TABLE VA

Plot Type A—Highland

	Sub-plot Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Grasses	Mulch Treatment*	X	M	A	S	X	M	A	S	X	M	A	S	X	M	A	S	X	M	A	S	X	M	A	S	
	Grass Source*	W	W	W	W	W	N	N	N	W	W	W	W	W	N	N	N	W	W	W	W	W	N	N	N	
	Andropogon gerardi	1	2	1	3	2	5	3	8	1	0	1	7	11	7	43	16	6	9	15	47	7	2	7	11	215
	Andropogon scoparius	1	4	3	1	5	0	1	1	0	0	2	12	6	3	8	2	0	1	4	32	2	0	0	2	90
	Panicum virgatum	0	9	1	1	6	18	5	4	1	0	6	6	2	0	12	2	1	6	3	15	2	3	7	8	118
	Sorghastrum nutans	8	9	3	7	0	31	4	5	2	4	6	17	14	14	13	4	4	11	17	15	0	11	6	11	216
	Sub-total Grasses	10	24	8	12	13	54	13	18	4	4	15	40	33	24	76	24	11	28	39	109	11	15	20	32	639
Legumes	Amoroha canescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lespedeza capitata	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
	Petalostemum purpureum	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Forbs	Eryngium yuccifolium	0	0	0	4	1	6	6	10	0	5	9	21	15	18	30	21	11	17	36	55	2	3	5	9	284
	Liatris (species)	17	28	9	34	28	2	0	0	15	14	29	65	57	1	4	5	69	90	109	174	24	2	0	0	776
	Parthenium integrifolium	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3
	Silphium (species)	2	10	2	12	9	17	10	11	3	2	5	22	6	19	15	11	6	8	7	26	7	12	7	8	237
	Ratibida pinnata	11	10	3	9	8	20	7	5	1	0	3	16	12	4	14	5	3	1	0	9	1	5	0	10	157
	Total	40	72	25	71	59	99	36	44	23	25	62	166	123	67	139	66	100	143	192	313	45	38	32	59	2,099

*Grass Source: W=University of Wisconsin Arboretum; N=Nebraska, Wilson Seed Co.
*Mulch Treatment: X=no mulch; M=marsh hay; A=UW Arboretum prairie hay; S=straw.

TABLE VB

Plot Type B—Steep Hillside

	Sub-plot Number	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	Total
Grasses	Mulch Treatment*	M	A	S	X	M	A	S	X	M	A	S	X	M	A	S	X	M	A	S	X	M	A	S	X	
	Grass Source*	W	W	W	W	W	N	N	N	N	W	W	W	W	N	N	W	W	N	N	N	W	W	W	W	
	Andropogon gerardi	4	4	3	4	5	2	0	0	0	2	1	1	0	13	4	5	1	12	7	1	6	0	3	1	
	Andropogon scoparius	1	6	1	2	2	1	0	0	0	4	1	0	0	8	3	2	4	23	3	0	11	3	1	3	79
	Panicum virgatum	0	2	1	0	2	2	0	0	0	1	0	1	0	4	2	2	1	3	4	2	4	1	0	0	79
	Sorghastrum nutans	3	3	1	0	1	3	0	2	0	0	1	0	0	9	4	1	0	5	2	0	1	0	1	2	39
	Sub-total Grasses	8	15	6	6	10	8	0	2	0	7	3	2	0	34	13	10	6	43	16	3	22	4	5	6	229
Legumes	Amorpha canescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lespedeza capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
	Petalostemum purpureum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Forbs	Eryngium yuccifolium	6	7	6	7	8	0	0	4	1	1	0	0	5	2	0	2	0	2	5	5	8	3	3	0	75
	Liatris (species)	37	32	14	38	28	0	0	0	0	3	6	32	1	0	0	26	11	1	0	0	40	39	5	2	315
	Parthenium integrifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Silphium (species)	5	6	3	5	4	5	3	6	2	3	4	1	1	12	1	5	3	6	10	2	11	8	3	2	111
	Ratibida pinnata	1	4	2	3	2	0	0	2	4	3	0	2	3	4	1	3	2	7	5	4	4	3	4	0	63
	Total	57	64	31	59	53	13	3	14	7	17	13	37	10	52	15	47	22	54	36	14	85	57	20	10	795

*Grass Source: W=University of Wisconsin Arboretum; N=Nebraska, Wilson Seed Co.
*Mulch Treatment: X=no mulch; M=marsh hay; A=UW Arboretum prairie hay; S=straw.

TABLE VC

Plot Type C—Lowland

		49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	Total
	Sub-plot Number	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	Total
	Mulch Treatment*	S	X	M	A	S	X	M	A	S	X	M	A	S	X	M	A	S	X	M	A	S	X	M	A	
	Grass Source*	N	N	N	N	W	W	W	W	N	N	N	N	W	W	W	N	N	N	W	W	W	N	N	N	
Grasses	Andropogon gerardi	1	0	0	2	3	1	5	5	20	1	1	11	8	34	19	0	26	7	2	1	1	0	1	1	144
	Andropogon scoparius	1	6	0	6	2	0	8	7	8	10	1	13	6	14	13	0	8	8	1	4	2	0	0	1	119
	Panicum virgatum	5	2	0	2	0	1	0	2	13	8	0	1	0	3	1	0	8	5	0	2	0	0	0	0	53
	Sorghastrum nutans	1	0	0	1	0	0	2	1	0	0	0	3	0	1	0	0	17	2	0	0	0	0	0	0	28
	Sub-total Grasses	8	8	0	11	5	2	15	15	41	19	2	28	14	52	33	0	52	22	3	7	3	0	1	2	344
Legumes	Amorpha canescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lespedeza capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Petalostemum purpureum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Forbs	Eryngium yuccifolium	11	6	4	2	4	7	12	8	15	2	4	2	3	0	2	1	7	0	1	3	1	0	0	0	95
	Liatris (species)	0	0	0	0	12	15	33	12	3	0	0	0	28	58	42	0	0	0	10	6	5	0	0	0	224
	Parthenium integrifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Silphium (species)	15	5	7	10	4	1	4	5	16	6	7	3	11	12	18	9	14	12	4	8	12	4	3	2	192
	Ratibida pinnata	9	1	5	1	2	1	3	1	7	8	0	0	3	4	0	1	3	13	3	3	2	0	0	1	71
	Total	43	20	16	24	27	26	67	41	82	35	13	33	54	126	93	11	77	47	21	27	23	4	4	5	926

*Grass Source: W=University of Wisconsin Arboretum; N=Nebraska, Wilson Seed Co.

*Mulch Treatment: X=no mulch; M=marsh hay; A=UW Arboretum prairie hay; S=straw.

TABLE VI

Mulch and Seed Type Variables, Summarized and Totaled

Sub-plot Type, Number, Treatment	Grasses	All Species
XWA		
1	10	40
5	10	59
9	4	23
13	30	123
17	11	100
21	11	45
Sub-Total	76	390
XWB		
28	6	54
36	2	37
40	10	47
48	6	10
Sub-Total	24	153
XWC		
54	2	26
62	52	126
Sub-Total	54	152
Total	154	695
Density per M²	51.4	231.6

	Grasses	All Species
XNA		
0	0	0
XNB		
32	2	14
44	3	14
Sub-total	5	28
XNC		
50	8	20
58	19	35
66	22	47
70	0	4
Sub-total	48	106
total	54	134
Density per M²	30.8	76.4

	Grasses	All Species
MWA		
2	24	72
10	4	25
18	28	143
Sub-total	55	240
MWB		
25	8	57
29	10	53
37	0	10
41	6	22
45	22	85
Sub-total	46	227
MWC		
55	15	67
63	33	93
67	3	21
Sub-total	51	181
Total	152	648
Density per M²	55.2	235.6

	Grasses	All Species
MNA		
6	54	99
14	24	67
22	16	38
Sub-total	94	204
MNB		
33	0	7
Sub-total	0	7
MNC		
51	0	16
59	2	13
Sub-total	2	29
Total	96	240
Density per M²	64	160

	Grasses	All Species
AWA		
3	3	25
11	15	62
19	39	192
Sub-Total	62	279
AWB		
26	15	64
34	7	17
46	4	57
Sub-Total	26	138
AWC		
56	15	41
68	7	27
Sub-Total	22	68
Total	110	483
Density per M²	52.2	241.6

	Grasses	All Species
ANA		
7	13	36
15	76	139
23	20	32
Sub-Total	109	207
ANB		
30	8	13
38	34	52
42	43	59
Sub-total	85	124
ANC		
52	11	24
60	28	33
64	0	11
72	2	5
Sub-Total	41	73
Total	235	404
Density per M²	94	161.6

	Grasses	All Species
SWA		
4	12	71
12	40	166
20	109	373
Sub-Total	161	610
SWB		
27	6	31
35	3	13
47	5	20
Sub-Total	14	64
SWC		
53	5	27
61	14	59
69	3	23
Sub-total	22	109
Total	191	783
Density per M²	87.6	348

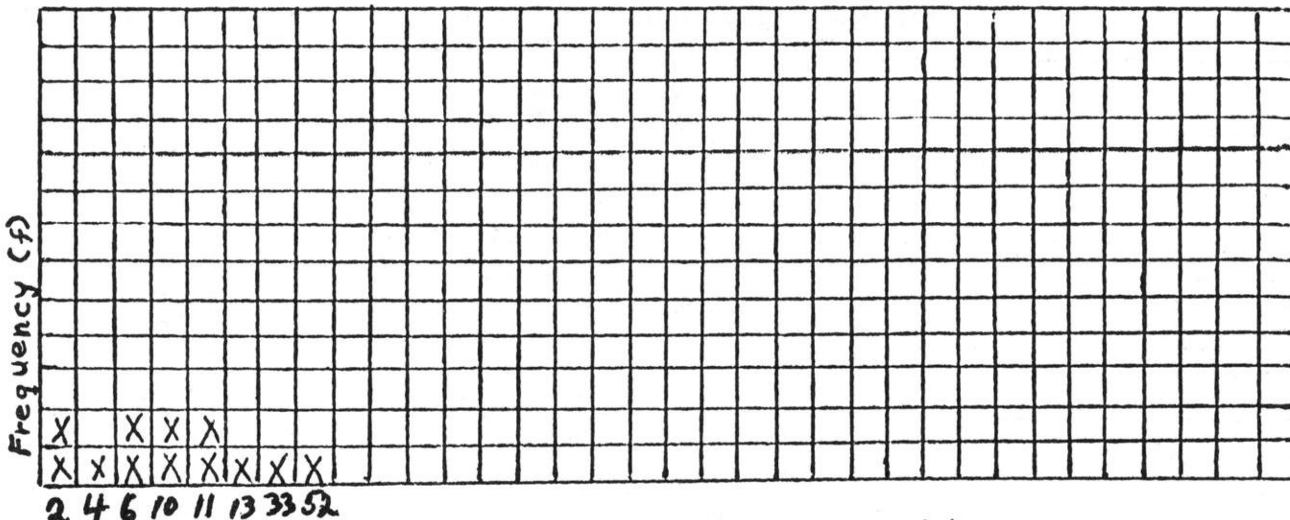
	Grasses	All Species
SNA		
8	18	44
16	24	66
24	32	59
Sub-Total	74	169
SNB		
31	0	3
39	13	15
43	16	36
Sub-Total	29	54
SNC		
49	8	43
57	41	82
65	52	77
Sub-Total	101	202
Total	204	425
Density per M²	90.8	188.8

MULCH TYPES: X=no mulch; M=marsh hay; A=arboretum hay; S=straw.

SEED TYPES: W=University of Wisconsin grasses; N=Nebraska grasses.

TABLE VII

(Sample Work Sheet)
Work Sheet for Population XW (Grasses)



Work Table

X	f	f(x)	f(x²)
2	2	4	8
4	1	4	16
6	2	12	72
10	2	20	200
11	2	22	242
13	1	13	169
33	1	33	1,089
52	1	52	2,704
Σ=	12	160	4,500

Calculations

Sample Values:

Number of samples (n) = sum of frequencies $= \Sigma f$ = 12

Sum of f(x) column $= \Sigma f(x)$ = 160

Mean or average $= \bar{x} = \frac{\Sigma f(x)}{n}$ = 13.3

Variance $= v = \frac{\Sigma f(x^2) - (\Sigma fx)^2 / n}{n-1}$ = 215.2

Standard deviation $= s = \sqrt{v} = \sqrt{\frac{\Sigma f(x^2) - (\Sigma fx)^2 / n}{n-1}}$ = 14.7

Standard error of the mean $=$ s.e.$\bar{x} = \frac{s}{\sqrt{n}}$ = 4.2

Mean $\pm$ 1 standard errors $= \pm$ 1 s.e.$\bar{x}$ = 9—17.5

Mean $\pm$ 1.96 standard errors $= \bar{x} \pm$ 1.96 s.e.$\bar{x}$ = 4.9—21.7

Population Parameter Estimates:

Population size $= 12(\bar{x})$ = 160

Standard error of population estimate $= 12$(s.e.$\bar{x}$) = 50.4

95% confidence interval for estimate of population size $= 12(\bar{x} \pm$ 1.96 s.e.$\bar{x}$) = 59—260

TABLE VIII

Statistical Comparisons of Means of Populations

STATISTICAL COMPARISONS OF MEANS OF POPULATIONS-TABLE VIII

Population (Grasses)		Probability Factor	Population (All Species)		Probability Factor
XW	XN	1.02	XW	XN	3.40
MW	XW	.11	MW	XW	.06
XW	MN	.28	XW	MN	4.20
XW	AW	.70	XW	AW	.13
XW	AN	1.20	XW	AN	.50
XW	SW	1.40	XW	SW	1.84
XW	SN	1.40	XW	SN	.90
XN	MW	1.30	XN	MW	2.90
XN	MN	.90	XN	MN	.30
XN	AW	1.00	XN	AW	2.00
XN	AN	1.95	XN	AN	1.60
XN	SW	1.10	XN	SW	1.70
XN	SN	2.30	XN	SN	2.60
MW	MN	.20	MW	MN	.90
MW	AW	.04	MW	AW	.09
MW	AN	1.20	MW	AN	1.10
MW	SW	.70	MW	SW	.70
MW	SN	1.40	MW	SN	.80
MN	AW	.20	MN	AW	.90
MN	AN	.60	MN	AN	.02
MN	SW	.40	MN	SW	1.10
MN	SN	.70	MN	SN	.04
MN	AN	1.20	MN	AN	.90
AW	SW	1.50	AW	SW	.50
AW	SN	1.30	AW	SN	.60
AN	SW	.10	AN	SW	1.10
AN	SN	.10	AN	SN	.40
SW	SN	.10	SW	SN	1.00

TABLE IX

(Sample Work Sheet)
Statistical Comparison of Means of Populations
XW and XN (Grasses)

(SAMPLE WORK SHEET)

STATISTICAL COMPARISON OF MEANS OF POPULATIONS XW AND XN (GRASSES)

Difference between the means = d = $(\bar{x}_{XW} - \bar{x}_{XN})$ = 5.60

Standard error of the difference between the means =

s.e.d. = $\sqrt{(s.e.\bar{x}_{XW})^2 + (s.e.\bar{x}_{XN})^2}$ = 5.50

Probability factor = k = $\frac{d}{s.e.d.}$ = 1.02

How to Get a Good Stand of Native Prairie Grass in Nebraska

JIM WILSON
Wilson Seed Farms, Polk, Nebraska

They used to say, "It takes five years to get a stand of native grass!" Not any more. You can have an excellent stand the second year, if you plant it right.

But what's right for one field may be wrong for another. What's right for the semi-arid western Great Plains, where the main hazards are drought and wind erosion, can be wrong for the fertile, high-rainfall Corn Belt, where grassy weeds are the hazard. What's right for a certain field for one reason may be dead wrong for another reason.

So what do you do? You study this article carefully, consult your local Conservationist, make a decision that you hope is more right than wrong, then leave it up to the grass. The first year, chances are you'll have a weed patch. If you don't get disgusted and plow it up, the second year you'll probably have a miracle.

Cool-Season Grass Is a Cinch

It's easy, of course, to get a stand of the quick-sprouting, fast-growing introduced cool-season grasses, like brome, intermediate wheat and orchard grass. Just plant on a reasonably hard, weed-free seedbed in late summer or early fall, when there's no weed competition. Even early spring seedlings usually make a good stand the second year.

With the warm-season natives, it's not quite so simple.

(In these planting instructions, select a seeding time to suit the warm-season grasses, even if the mixture also includes a native cool-season grass like western wheat or green needle. If it includes an introduced cool-season grass, that's a special case, which I'll explain later.)

The SCS Led the Way

Years ago, the Soil Conservation Service learned that the best way to get a stand of native grasses on the light soils of the wind-swept, semi-arid West was to work the ground—shallow—till mid-summer, plant a solid-stand cover crop to forage sorghum or sudan grass, cut it in the fall, leaving a 10 to 14 inch stubble, then plant locally adapted seed (Write for my reprint, "There's Grass Seed — And Grass Seed," from the Nebraska Range Management Newsletter.) in the undisturbed stubble with a Nisbet-type grass drill.

This drill was developed by SCS personnel in the '40's, and with recent improvements it's still the best machine made for planting all kinds of grass and legumes. It has double-disc furrow-openers with depth bands, dual seedboxes with agitators, and spring-tension packer-wheels. It will plant almost anything from pepper to feathers. It plants all types of seed at once at exactly the right depth, regardless of the condition of the soil, packs the rows and leaves the space between level and cloddy, with no ridges to wash in on furrows, if it rains. Stalks and stubble won't clog it, and if you keep the discs sharp and plant in dry weather, it will cut through plenty of trash.

There are now about 300 Nisbet drills in Nebraska, owned by seed dealers, banks, conservation districts, contractors, farmers and ranchers. You can rent one for $1.00 or $1.25 per acre, save half your seed bill, and get a better stand. At the Wilson Seed Farms we have nine that we rent to seed customers. Write us for complete instructions for planting with a Nisbet drill. It's an art!

When To Plant?

The SCS formula for planting native grass has never been improved on for the western Great Plains. It provides a good hard seedbed, and the cover crop prevents wind erosion, suppresses the characteristically sparse weed growth, retards evaporation, and protects the tiny grass seedlings from wind damage.

Or you can plant in the stubble of a last year's dry-land milo or corn field. (Irrigated fields may have to be lightly disced to level the ridges and grind up the trash.) Clean wheat stubble will serve in a pinch, if there isn't too much volunteer, but it may take an extra season for a full stand to develop. We've also heard of farmers who like to plant oats in the fall, let it winter kill, and seed in the dead growth, but don't say we told you to do it! Cane-type stubble makes the best cover and does the best job of suppressing weeds.

If you plant native grass on undisturbed stubble, either make a "dormant seeding" late enough in the fall—after mid-November in Nebraska—so the seed doesn't sprout till spring, or plant in the spring, early enough so the grass gets a fair start with the weeds. Spring seedings usually make better stands, but sometimes it's hard to rent a drill in the spring. Don't plant in late summer or early fall—the warm-season grasses will probably sprout and winter-kill.

Grassy Weeds

The stubble-seedbed formula also works for the Corn Belt, on land reasonably free from foxtail and barnyard grass seed.

But if your land is infested with annual grasses, look out! In the fertile, high-rainfall Corn Belt, especially on irrigated land, there are fields so foul with grassy weeds that the planting of a cover crop the year before won't even discourage them. They can completely obliterate a seeding of native grasses the first season.

Broadleaf weeds aren't a serious problem, unless you have a fairly solid carpet of pigweed, or something like it. After you clip broadleaf weeds, they grow back straight up, without spreading out. I've seen excellent native-grass stands develop in forests of sunflowers and cockleburs. But when you clip grassy weeds, they grow back flat to the ground, sprawl out and smother everything in sight. Ever notice foxtail in a lawn that's been mowed?

What to do?

There are several possibilities. In our heavy eastern Nebraska soil, we've been getting good stands of native grass on reasonably level fields infested with foxtail and barnyard grass by working the ground, shallow, four times through the spring and early summer, to sprout and kill four crops of grassy weeds—you need rains, of course, to sprout the weeds—then planting in June or early in July, after the first weed-growth season is over. (You can't plant this late in the semi-arid West, but here we usually get enough summer moisture to plant native grass clear up to late July with reasonable assurance that it will sprout and make enough growth to get through the winter.)

We know the late planting date, after successive weed-killings, makes a difference. In 1962, a Merrick Co. farmer planted half of a foxtail-infested field on June 14th, and got a marvelous stand. The next year, he jumped the gun and planted the other half on May 15th, and lost the whole seeding to foxtail.

The Question of Plowing

True, grass likes a hard, undisturbed seedbed. The harder, the better. But don't roll the ground. It encourages weeds between rows. If you work it no deeper than two or three inches and plant with a Nisbet drill, the packer wheels will give you a hard enough seedbed where it needs to be hard—in the row.

In fact, we've found that you can even plant on plowed ground with a Nisbet. (In the old days, when native grass was all planted with a fertilizer spreader or grain drill, plowing was an almost certain invitation to failure.)

More and more of our cooperators report that the best way they've found to lick the grassy-weed problem, on land that doesn't wash or blow, is to turn the weed seed under deep enough so it won't sprout the first spring.

"I plow in late summer or fall," says Harold George, of Dixon County, "let the ground settle through the winter, disc and harrow in the spring, and plant in April. If there's a lot of trash, it should be burned or taken off before plowing, so the plowed layer won't dry out. And of course you have to disc shallow, so as not to turn up weed seed."

If your land is so steep that it washes, and you've got foxtail, too, you have a hard choice. You should probably plant in sorghum stubble and figure it may take an extra year to get a good stand.

Suppose that, instead of foxtail and barnyard grass, the weed is crabgrass, which comes on late in the summer? Then, if your land is too steep or sandy to plow, all you can do is to plant early on an undisturbed cover-crop seedbed, and hope the new seeding is far enough along by late summer to survive the onslaught of the enemy.

Remember, if you work the ground, work it right up to planting, and plant late. If it rains before you get the job done, work it again, to give the grass an even chance with the weeds. If you plant on undisturbed stubble, plant early enough so the seed will be there to sprout as soon as the ground warms up—November 15 to May 15 is probably the best time for Nebraska.

Native Grass After Soybeans?

Soybean stubble! This may be the best seedbed of all for native grass in the Corn Belt. We've tried it three times at Wilson Seed Farms, each time with a perfect stand. The Cook Co. (Ill.) Forest Preserve District got a better stand on soybean stubble than on any other seedbed.

There seems to be something about soybean ground that encourages perennial grass seedlings and discourages weeds. We can't explain it. It may even be our imagination. But try planting native grass in undisturbed soybean stubble about April 15th and let us know what happens.

For a Good Stand of Trefoil or Crownvetch

If you include birdsfoot trefoil or crownvetch in the mixture and both compete successfully with both native and introduced grasses in eastern Nebraska—you should plant before mid-July at the very latest—preferably in April or May. Fall planting is out, especially for trefoil. The roots are so tender that if the plant doesn't go into the winter with a good growth, the heaving of the ground will tear it apart. And crownvetch grows almost as slowly as native grass the first few weeks.

Like alfalfa, birdsfoot trefoil will freeze if it sprouts too early. But it contains enough hard seed—up to 40 or 50%—so that, if for some reason you have to make a dormant fall seeding, enough seed will sprout late in the spring to give you at least a fair stand. And, unlike alfalfa, trefoil will reseed and thicken up, especially after cattle start trampling the field. Frost rarely hurts crownvetch.

Never plant trefoil on ground that's been sprayed with 2-4D that same season. It's very sensitive to the residual effect for weeks afterward. And be sure to use trefoil inoculant—double strength, with skimmilk as the wetting agent, three cups to the bushel.

All-Season Pastures

More and more eastern Nebraska and Corn Belt farmers are experimenting with the new "all-season pastures"—a mixture of warm-season natives plus a sprinkling of a high-producing introduced cool-season grass and perhaps a legume. (Write for reprint of my articles, "Can We Have All-Season Pastures?" and "How To Start And Manage An All-Season Pasture," in the Nebraska Farmer for Jan. 2 and Jan. 16, 1965.)

We used to think such pastures should be planted late enough in the spring to penalize the cool-season grass somewhat, so the late-sprouting warm-season grasses could compete with it. However, we've found that the proportion of the two types of grass in the mixture is much more important than the planting date, for getting a balanced stand. If you use a non-competitive cool-season bunchgrass, like orchard, plant about 6 live seeds per square foot—.4 lb. PLS of orchardgrass—to 24 of the warm-season grasses. If you use a sod-forming grass like intermediate wheat, plant 4 live seeds to 24 of the other. Obviously, the bunchgrass has some advantage. Sterling Orchardgrass is ideal for eastern Nebraska.

We have planted all-season pastures successfully in every month from November to July, but May is probably the best month in Nebraska.

No Nurse Crops!

Should you plant a nurse crop with grass? No. The slow-starting grass doesn't need any competition from a fast-growing nurse crop.

However, several farmers have told us that, in these all-season pastures, the light sprinkling of introduced cool-season grass appears to have all the advantages of a nurse crop for the warm-season native grass, with none of the disadvantages, and gives them a better stand of native grass than if they had planted it alone.

We're not ready to go out on a limb and say it always works this way, but if it does, the explanation might be as follows:

You always get a lot of annual weeds the first year in a new seeding of straight warm-season grass, and these weeds use more and more moisture and fertility as the summer progresses, and take up more and more room. The early growth of the cool season grass keeps a lot of these weeds in the row from sprouting and developing; then, with hot weather, the cool-season grass goes dormant and uses very little more moisture and fertility till fall.

What about fertilizer? No nitrogen the first year, or until you get a full stand. The weeds will get all the benefit from it and crowd out the grass. There's always enough nitrogen in the ground to start native grass. In fact, you'll get your best stand in what looks like pure clay. If the soil needs phosphorus or other elements, apply before planting. (Write for reprint of my article, "Fertilizer on Grass," from the Nebraska Farmer for March 3, 1962.)

Grass Seeding Rates

Because of the great variation in quality of native grass seed, almost everyone now figures seeding rates in pounds of Pure Live Seed (PLS), instead of bulk pounds. (Write for reprint of my article, "How To Buy Grass Seed," in the Nebraska Farmer for March 19, 1960.)

How many live seeds per square foot do you want to plant? At present, the SCS suggests a minimum of 20 per square foot for the semi-arid West, 20–30 for eastern Nebraska dry land, 40 for irrigated land, and 50 for dams and waterways. The amount may be divided between four or five kinds, in different percentages, depending on the site and local conditions.

Your Work Unit Conservationist will know what you should plant. (Write for reprints of my articles, "What Do You Know About Grass?" in the Nebraska Farmer for April 18 and May 2, 1964.) He has a table giving the number of live seeds per square foot from one pound of Pure Live Seed per acre, for each kind of grass. (One pound will give you all the way from 1.3 seeds per square foot for buffalograss to 30 for sand lovegrass.) From this table he can figure how many pounds of PLS per acre you need of each kind. Or you can write us for the table and do it yourself. Your seed dealer will figure how many pounds of bulk it takes to make that many pounds of PLS.

Cheap Seed's Too Expensive!

Don't try to economize with "bargain" seed. It's no bargain. The Purity doesn't matter, as long as you don't have to pay for the straw and it will feed through the drill. The Germination matters a very great deal—much more than you'd suspect from the figures.

In low-germ seed, even the live seed is weak and won't survive as well in the field as the laboratory test indicates. If one pound of 80% germ seed will make a good stand, it may take eight pounds of 40% germ seed. (Write for reprint of my article, "There's Grass Seed — And Grass Seed," in the Nebraska Range Management Newsletter.)

If at all possible, buy certified native grass seed produced in cultivated rows. It will usually give you a far better stand than seed harvested from wild native pastures. I'll tell you how we know this. In the days when there was certified Indiangrass but only wild-harvest Big Bluestem, it was hard to find any Big Blue in new seedings, even though the SCS and ASCS offices often included almost twice as much Big Blue as Indian in their recommendations and the number of seeds per pound PLS is almost the same for both. Today, with certified big blue available also, there's plenty of big blue in the seedings where it's used.

Special Problems

We're often asked, "Can you drill warm-season native grass into an old brome pasture?"

You can, but you won't get a stand for several years. By the time the warm-season grass sprouts in the spring, the brome is already well advanced. It's much better to get rid of the brome and start over. Usually the brome is so sod-bound that it isn't worth saving anyway.

Says Harold George, of Dixon County, "To kill brome, I plow in the fall, when it's about six inches high and growing vigorously. If you plow in the spring, or in summer while it's dormant, you're only cultivating it!" A couple of discings in the spring will usually kill the few plants that survive the winter.

On rough land, the SCS recommends a cover crop the first year, to anchor the soil. Usually, however, the network of brome roots will prevent washing until the new seeding establishes itself.

Instead of plowing, Harold Klingman—Work Unit Conservationist of Hall County, farther west—advises discing three or four times with a sharp, heavy tandem disc. "It saves moisture," he says, "and there's less danger of washing, with the growth on the surface." In any event, the first tillage operation should be performed in the fall when the brome is actively growing.

What about adding cool-season grass to an established warm-season pasture? Yes, you can do that, if it isn't already infested with low-producing bluegrass. Plant early in the fall. The cool-season grass will have two growing periods to get established, before the warm-season grass becomes active. It may need some nitrogen, though, to get started.

How To Start Over

The carrying capacity of old worn-out native pastures, from which the good grasses have been driven out by years of overgrazing, can be increased up to 800% by re-establishing those grasses. On hard land, the quickest way to do it is to get rid of the "junk" grass and weeds, as previously explained, and start over.

If the soil's too sandy for this, interseed. The interseeder skims off bare strips 30 or 40 inches apart, and plants a row of grass in each strip, leaving strips of old sod between to keep the field anchored. With three to five years of rest and good management, the new grass will crowd out the old.

Do you have a basin completely taken over by sedges, water grass, or coreopsis, where you'd like to plant reed canarygrass? Plow it and work it down as soon as it dries out in the summer, and plant in August. Overflow creek land foul with weed seed can be reclaimed the same way.

How about that old alfalfa patch that you'd like to convert to native grass pasture? If it's foul with grassy weeds, you'll have to plow, as previously explained—and you should probably raise a crop of milo or corn the first year, to use up the surplus nitrogen. However, if the patch is nice and clean, you can spray with 2-4D to kill the alfalfa, and plant right in the sod. If you don't get a good kill the first time, give it another shot after the grass is an inch high. (Watch closely for grassy weeds, too, and clip first, if necessary.) Planting directly in alfalfa sod, of course, isn't for "dry country."

When all's said and done, it's hard to beat sorghum stubble as a seedbed for grass, on most sites.

Off to the Races!

You have planted the best quality grass seed available, with a Nisbet-type drill, in the right kind of seedbed, at the right time of year. Now there's nothing to do for a time but wait and watch the weeds grow!

In about two weeks the tiny grass seedlings will appear in the row, needle-thin and all but invisible in the weeds. They'll get about half an inch to an inch high, then grow down, instead of up, for a while. They've learned from centuries of experience with Nebraska droughts not to risk their lives for the sake of display. (This is when it encourages a fellow to have a few spears of orchard or intermediate wheat grass in the row!)

The Weeds Can Still Win

Meanwhile, the weeds tower and spread. When they shade about 70% of the ground, shred them back to the height of the perennial grass seedlings. It doesn't hurt to clip a few leaf-ends, but don't cut off the growing point of the grass.

Don't use a mower. It lays the stuff down in a solid swath to smother the tiny seedlings. Use a rotary shredder. And if you've planted an all-season pasture, remember that to the warm-season grass, the introduced cool-season grass is a weed the first year. Shred it back to the height of the warm-season grass, along with the foxtail and pigweed.

Should you spray? Not unless at least 30% of the weeds are broadleaf. There's no spray for grassy weeds that won't also kill perennial grass seedlings. Spraying with 2-4D actually stimulates the grassy weeds. Spray or no spray, you have to shred them. With the broadleaf weeds dead, the grassy weeds will grow back flat to the ground and smother everything in sight. It's usually better to leave the broadleaf weeds alive to grow back, too, and act as a control on the grassy weeds.

Success at Last!

You'll probably have to shred twice, maybe three times, the first year. Neglect it, and you may well lose all you have spent on your seeding and have to start over..

Do your duty, and when frost drives the green from your field and the foxtail collapses in a washed-out, sodden mat, you should see, standing crisp, curly and russet-brown in the rows, those magnificient gifts of the gods to the prairie—the lovely native grasses. Some may even be headed out.

Graze your new seeding lightly the next year, and give the roots a chance to stretch down to China. (Write for our leaflet, "How To Manage Your Grass.") The third year, you should have a stand that will be a thing of beauty, a joy and a jackpot till the next Ice Age, if you live that long and treat it right!

A Practical Restoration Method for Tall-Grass Prairie[1]

PETER SCHRAMM
Department of Biology, and Director of the
Biological Field Station, Knox College, Galesburg, Illinois

Introduction

With the disappearance of most of the original tall grass prairie from the midwestern scene, there has been, in recent years, an increased interest in the possibility of replanting and restoring a part of this diverse and beautiful grassland community. In 1955 attempts to restore prairie on the Knox College Biological Field Station were begun. In the past few years, these efforts have been greatly expanded with the use of machinery to speed the rate of restoration and to improve the quality of the results. It is important to point out that a restored prairie is a far cry from the original thing, greatly lacking in diversity and proper composition. Some species we do not know how to reestablish. Others are difficult, but possible, and still others are fairly easy to get established. Though not the original, the restored prairie has much to offer in beautifying the landscape, restoring the quality of the soil upon which it is established, offering a rich habitat for bird and animal life, and, finally, giving us a fair glimpse of what our original midwestern environment was like. Furthermore, a restored prairie will improve with age.

This paper describes the methods that have been used with good success on the Knox College Biological Field Station located 20 miles east of Galesburg in Knox County, Illinois. These methods can be used in a small garden plot, doing the work by hand, or applied on a larger scale operation such as a highway planting program.

Obtaining Seed

Gathering of seed for Illinois prairie planting may be the most arduous part of a restoration project. Seed of the various species of grass may be hand-picked (or combined) in the early fall, *when ripe*. Groups of students or boy scouts with paper bags may be recruited for this work.

Large operations such as highway planting projects may establish some prairie grass plots specifically to be used as seed sources. These may be combined regularly, when ripe (mid-September to early October, depending on conditions). A well-established, dense planting may produce a harvestable quantity of seed in two to four years after planting.

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[1]Although this paper was not formally presented in the restoration session, this method was described during a guided tour of the prairie restoration project on the Knox College Biological Field Station, and hence, is included in these proceedings.

For the initial plantings, prairie grass and forb seed may be picked along railroad right-of-ways, along back county roads, road banks that are too steep for mowing and around the edges of old country cemeteries. Such areas may never have been plowed and represent remnants of the original prairie. Some such remnants may even be accessible to machine combining of the seed.

Commercial Source

Seed of several of the most important grasses may be obtained commercially from Jim Wilson, Wilson Seed Farms, Polk, Nebraska. These varieties from Nebraska seem to do quite well in the higher rainfall areas such as Illinois, and may be successfully used to augment initial plantings.

A list of recommended grasses and forbs (non-grass plants, such as prairie wild-flowers) are appended at the end of this paper.

Conditioning of Seed

Native seed (both grasses and forbs) gathered from local sources should go through a cold-damp conditioning or "stratification" to insure good germination. This is also recommended for commercial seed. Mix the seed with about ½ its volume of *damp* vermiculite soil conditioner. Large plastic garbage cans may be used to store this mixture. The mixture is then placed in cold storage at around 34° F for from *two to three months*. The Knox project places seed in the local locker plant about mid-March for an early June planting. Freezing does not hurt the seed. Temperatures above 38° F are to be avoided as mildew may occur.

Ground Preparation

Thoroughly plow area to be restored. Plow, preferably in the fall, so that frost may get at perennial roots; however, plowing may be done at other times of the year if necessary to get project under way.

Weed Control and Reducing Competition

The main problem of prairie restoration is to keep to a minimum the weeds (particularly the annuals) that compete with the newly established prairie plants. *Once the prairie plants are well established they will keep out further weed invasion.* If the project timetable necessitates, planting may be done late the following spring after plowing, but it is best to leave the field fallow for one year, keeping it weed-free by *regular shallow* discing and/or harrowing. If possible, keep a wide strip around plowed area mowed and free of weeds that could seed into the area.

Time of Planting

One and a half years later, in *late* spring-early summer (no earlier than late May, no later than late June) planting may be made. This late planting date allows for harrowing of germinating weeds up through the late spring.

Preparation of Seed Bed

Prepare the seed bed for planting with a final harrowing or shallow discing. (Deep discing will bring up more weed seeds.) *DO NOT APPLY FERTILIZER.* Fertilizer will only increase the vigor of the competing annual weeds.

Planting

The seeds are planted in damp condition, just as they come from cold storage, mixed with the vermiculite. The seed (both grass and forbs) may then be planted by hand-broadcasting or by a seed drill machine. A very rapid and easy method of hand-broadcasting areas of from one to several acres is for three persons to hand-broadcast from the back of a small tractor-drawn trailer containing the seed.

Rate of application will vary, depending on the amount of seed available, and the size of the area planted. It has been found that the denser rate of application of grass seed will result in a restored prairie *sooner* than a more thinly scattered planting. A very thinly scattered planting might take from eight to ten years to look like a restored prairie, but would result in a much larger area planted. *The denser plantings in small areas are much preferred.* A reasonably dense planting should have from one to three dozen grass seeds per square foot. Further information on application rates can be obtained from Jim Wilson, Wilson Seed Farms, Polk, Nebraska.

Rolling in

Immediately after planting, the area should be lightly harrowed (or raked) and *thoroughly rolled.* The Knox project uses an over-sized metal lawn roller, water-filled and drawn by tractor. Even large plantings can be quickly rolled with such a set-up.

This rolling-in step is *very important* for it sets the seed into the soil for best germination results. Small plots can be hand tamped if a roller is not available.

Germination

Late June and early July rains are needed for germination and survival of the seedlings. If conditions are very dry, overhead watering of the planting may be necessary at this critical stage, but this is rarely needed in the high rainfall areas of the Midwest. By mid-August, the seedlings, though only a few inches high, have put down a deep root system and can survive the dryer conditions of late summer and early fall.

Control of Weed Competition After Planting

Competition and shading by vigorous annual weeds may be reduced by mowing whenever the weeds get above the height of the small prairie seedlings. The Knox project uses a large tractor-drawn rotary mower set to mow above the young prairie seedlings. Such mowing is important during the first growing season, and may be very helpful if continued into the second and possibly a third season. Take care not to mow the prairie plants themselves. A denser planting, well established, usually need not be mowed after the first year.

Use of Fire to Aid Establishment

Many prairie plants are resistant to and apparently stimulated by fire. Fire, if properly applied, will greatly aid in the establishment of newly planted prairie. Studies at the Knox Field Station have concluded that early spring, specifically the last week in March or the first two weeks in April, is the best time to burn prairie plantings. Some dense plantings may be burned the first spring after planting. Most plantings have enough dry plant fuel to get a good burn the second spring after planting. Burning is a great aid in eliminating perennial weeds and definitely stimulates the prairie grasses to increased growth. *Stands should not be burned in the fall* as this eliminates important winter plant cover for wildlife.

Evaluating Results of the Planting

Planting of prairie species may not result in the immediate, spectacular results of certain pasture grass plantings. Most of the prairie plants remain small the first season or two, and may be quite inconspicuous in amongst the annual weed growth. But they are there, nevertheless, and the fact of their establishment will be well apparent by the second or third growing season. From here on, only time and a minimum of management will result in a pleasing and natural landscape of great beauty. In a very few years such a restored prairie becomes completely self-maintaining.

Recommended List of
Easily Established Prairie Plants

The following lists of prairie grasses and forbs are known to readily establish by the above described planting methods.

THIS PARTICULAR LIST has been compiled rather specifically for such projects as *HIGHWAY PLANTINGS* where ease and success of establishment is imperative. (The forb list could be greatly expanded in smaller plantings where special hand-weeding methods could be employed.)

The dominant plants of any grassland community are the grasses, generally few in numbers of kinds (species) but very numerous in numbers of individual plants. Unlike most of the cool-season pasture grasses which turn a drab tan in winter, these warm-season species of native prairie grasses lend very special color to the landscape from late-summer through fall, to late winter. The color varies with the species and changes gradually as the season progresses.

Scattered amongst the grasses are many different species of forbs (non-grasses, such as wildflowers).

In native and restored prairies, the forbs give an ever-changing panorama of color as each species flowers at its particular time in the growing season.

For restoration, then, the basic mix is one of *grasses*, with various forbs added, depending on the species and amount of seed available.

GRASSES

Andropogon gerardi — Big Bluestem
Fall color: medium purple-maroon

Sorghastrum nutans — Indian Grass
Fall color: slightly maroon to more yellowish tan

These two grasses are highly recommended as a basic mix and can be planted in equal amounts, mixed together, or in separate stands, if desired. They do well in medium moist to slightly drier sites.

Andropogon scoparius — Little Bluestem
Fall color: deep maroon

For added variety this smaller and very colorful grass may be mixed in with the above in varying amounts. This species is particularly well adapted to very dry sites such as west or south-facing road banks. Such banks can be stabilized with this species. This species retains its deep maroon color until quite late in the season.

Panicum virgatum — Prairie Switchgrass
Fall color: yellowish

This species may also be added to the basic mix, in varying amounts, to give additional variety. It does particularly well in the damper sites, but will thrive in other areas as well.

FORBS

*Quick to become established and become apparent.
**Particularly quick to become established and flower.

Baptisia leucantha	White False Indigo
Baptisia leucophaea	Cream False Indigo
**Desmodium canadense*	Showy Tick trefoil
***Echinacea pallida*	Pale Purple Cone Flower
***Echinacea purpurea*	Purple Cone Flower
**Eryngium yuccifolium*	Rattlesnake Master
***Helianthus mollis*	Downy Sunflower
**Helianthus laetiflorus v. rigidus*	Stiff Sunflower
***Heliopsis helianthoides*	False Sunflower
**Lespedeza capitata*	Round-headed Bush Clover
Liatris aspera	Rough Blazing Star
Liatris pyncnostachya	Prairie Blazing Star
Petalostemum candidum	White Prairie Clover
Petalostemum purpureum	Purple Prairie Clover
Pycnanthemum virginianum	Mountain Mint
***Ratibida pinnata*	Yellow Prairie Coneflower
**Silphium laciniatum*	Compass Plant
**Silphium terebinthinaceum*	Prairie Dock
**Solidago rigida*	Stiff Sunflower
Veronicastrum virginicum	Culver's Root

Note: Legumes, for best results, should be inoculated with the appropriate *Rhizobium* bacteria (available commercially) just before planting.

Prairie Restoration and Experimental Design

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Introduction

Most prairie restoration and establishment projects have been undertaken for the protection and preservation of tall grass prairie biota or remnants of this vegetation type. Most of these are being used extensively for educational or demonstration purposes, but in general little attention has been given to the opportunities for experimental work which the projects afford. Two such projects, one at Argonne National Laboratory in northern Illinois, and one at the Kellogg-Gull Lake Biological Station of Michigan State University, near Kalamazoo, Michigan, are being initiated primarily for experimental purposes. In both cases the ultimate goals are contingent upon the eventual establishment of a biota characteristic of the original prairie ecosystem. This paper is concerned primarily with problems associated with the Gull Lake site.

A large number of plant species generally associated with the tall grass prairie are widely distributed in Michigan, and though they are now decidedly rare, relict prairies occurred over much of the Michigan lower peninsula (Transeau, 1935). The few relicts in southern Michigan which are still recognizable as such, are strongly suffused with adventive, introduced species and many indigens not normally considered to be prairie species. The extent to which the latter group of plants played a role in pre-settlement prairie vegetation is unknown. Most are plants confined to wetlands and forest edge in the more western prairie region, and their more frequent occurrence or increased importance in the Michigan prairie may simply reflect the west to east change along climatic, geographic and vegetational continua. Alternatively, it may be the result of post-settlement influences such as landscape manipulation, fire protection, grazing and the incursive influence of weedy exotics.

The present day composition of prairie relicts in the Kalamazoo region is relevant to our project as we are attempting to establish an ecosystem which will ultimately develop the characteristics which made the original prairies unique. The question of what to model it after is a nagging one, as there is a considerable degree of uncertainty surrounding extant models, and there are no substantive data on prairie composition from early post-settlement time.

Prairie Restoration Design

The Kellogg Biological Station project centers on a rectangular four hectare site completely surrounded by cropland. The site itself, however, has never been plowed. The original vegetation is assumed to have been oak-opening or oak dominated deciduous forest at the time of settlement. More recently and until the autumn of 1967 the site supported an open shrub and tree sprout growth, with an herb layer composed chiefly of indigenous species characteristic of forest openings and advanced successional communities. The larger woody species were mechanically removed and site preparation started in June 1968.

Two levels of treatment are being applied to the site, employing a stratified, random block design. The first level involves a marl application to one-half of each of the 4 1-ha blocks. The second level involves manipulation of initial species mix applied to 1/16 th. ha ($625 m^2$) plots within each 1 ha block. This allows 4 replications of 7 species combinations and the matrix vegetation (extant vegetation) each, under marl and non-marl treated conditions.

In addition, control burning will be conducted, either routinely or introduced as an additional variable set.

Seed material selected for introduction onto the site has been hand collected from isolated populations of prairie species and from prairie relicts in the southwest Michigan region, primarily from St. Joseph and Kalamazoo Counties. The decision to utilize local materials only is purely arbitrary, however there is some evidence that distinct genetic differences may exist between populations (and species arrays) which occur in both the northern and southern lower peninsula of Michigan. Therefore, only those populations native to the area of the project are being used for a seed source.

Seed mixtures applied to each set of replicate plots will vary from dicot herb dominant with grasses occupying subordinate positions; to equal proportions of all species; to grass dominant with dicot herbs occupying subordinate positions. Portions of each treatment may receive multiple seed application (as supply permits), and it is anticipated that, at some future time, additional species may be introduced.

Experimental Potential of Prairie Restoration and Establishment Projects

Aside from providing empirical information on the advisability and effectiveness of various site treatment procedures and seed mixtures employed in prairie species establishment, designs such as the one just described permit investigation of a number of fundamental ecological questions. These fall into two general categories; a) community organization and b) ecosystem dynamics.

Community Organization

Data from several sources (Drew, 1947, Weaver, 1954, Curtis, 1959) and others, suggest that in prairie (as in other vegetation types) there is a particular dominance heirarchy (sensu Whittaker, 1965) associated with a given position on soil drainage or other environmental gradients. Generalized models derived from these sources can be tested through variable seed input into relatively uniform field conditions. Recognizing a number of assumptions, e.g., equal probability of establishment and survival of all species introduced, etc., two alternative outcomes are possible; either all mixtures will tend toward the development of one species array, or, all mixtures will stabilize with differing proportions of the component species dependent upon the initial inoculum. Although stabilization is not likely to occur for many years, trends might appear relatively soon which could be detected using appropriate sampling techniques.

Related questions such as establishment and development of intra-community pattern (sensu Kershaw, 1963), and species associations within prairie vegetation could be approached in a similar manner.

Productivity and Nutrient Cycles

Another aspect to which prairie restoration projects in general lend themselves, is that of the investigation of productivity and mineral nutrient cycles. In view of the widespread establishment of totally synthetic species arrays over extensive areas once occupied by prairie vegetation, a comparative study should be undertaken to examine the relative effectiveness of these arrays at utilizing and/or conserving their resources. The stability of the grassland biota within the range of climatic fluctuation under which it evolved is well documented (Weaver and Albertson, 1956), yet the prairie is being replaced, inadvertently or otherwise, by exotic and untested species arrays. This loss of "native" genetic information may prove to be extremely serious in the future, and is nowhere as nearly complete as in the tall grass prairie region.

Experimental evidence needed to illuminate some aspects of these problems must employ a design which allows critical examination and comparison of exotic species, synthetic arrays and prairie species in close juxtaposition. Much of our right-of-way and abandoned agricultural land is 50 to 100 per cent non-native vegetation, ill-adapted to non-manipulative land use. How these arrays compare with native arrays in regard to such features as moisture utilization, nutrient uptake, retention and cycling, productivity and plant-soil relationships is the kind of information needed by public and private land managers for effective administration. Changes in the ecosystem associated with prairie biota establishment could and should be monitored in many of the prairie restoration projects currently being undertaken, even though many lack the facilities for manipulation or replication. The results of such studies might suggest immediate application, e.g., if prairie arrays were found to be an efficient sink for nutrient leakage from agricultural runoff, or harbored fewer agriculturally important insect pests or disease organisms.

No vegetation type in North America is in such immediate danger of irrepairable modification or loss as some of our grassland or prairie types. Asthetic reasons have been demonstrably ineffective in changing land use policies. Now we must turn to rigorously defendable, ecologically and economically sound, experimentally based information to reshape and redirect those policies.

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