rming Practices for a Sustainable Agriculture in North Dakota

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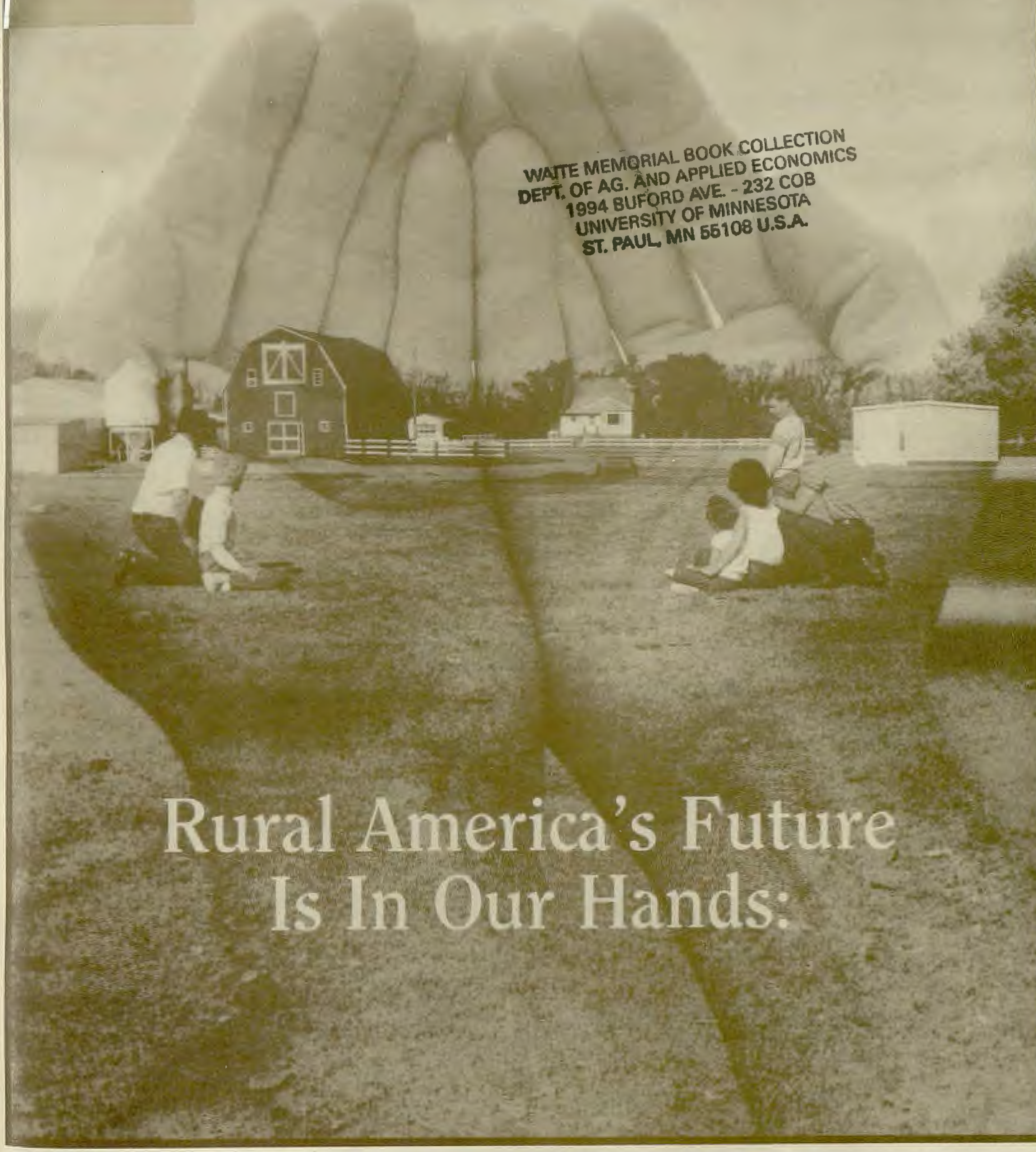

Rural America's Future Is In Our Hands:

Farming Practices for a Sustainable Agriculture in North Dakota

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Farming Practices for a Sustainable Agriculture in North Dakota

Summary and Conclusions

More information is needed on the ecological impact of various alternative farming practices in North Dakota. Farmers need comparative data to help them decide how to best meet the challenge of achieving economical yields while also maintaining high quality soils, water, and food. Policy makers need site specific information to help guide and shape environmental policy to be both broadly applicable and locally sensitive. This study was undertaken during the 1990 and 1991 crop seasons to compare what were deemed the most successful of alternative farm practices in North Dakota. Two farmer organizations, the Manitoba/North Dakota Zero-Till Association and the Northern Plains Sustainable Agriculture Society, both whom have championed alternative practices aimed at sustainability, helped define the objectives and choose actual farms to study. Successful farms representative of 1) practices predominately used, 2) maximizing use of conservation (or no) tillage, and 3) maximizing use of crop rotations to reduce (or eliminate) use of agrichemicals were chosen in eastern, central, and western North Dakota. As a benchmark of comparison, undisturbed prairie sites of similar soils were included within each region.

The principle findings include the following:

• Agricultural soils differed from prairie soils most in the east, and least in the west. Conventional practices had depleted soil organic matter contents by 71%, 57%, and 27% from the level fond in prairie soils in the east, central and west, respectively. In addition, prairie soils generally had larger aggregates, lower bulk density, and lower quantities of nutrients in mineral forms.

• The conventional farms generally performed the greatest amount of tillage, followed by the organic farms. Tillage tools used among farms were similar among the conventional and organic farms with the exception of plowing green manured alfalfa and sweet clover on the organic farms in the central and east.

• The no-till and organic sites had a greater proportion of large soil aggregates in the central and east as compared to the conventional sites, making these soils less vulnerable to wind erosion.

• Of the few farm sites which exceeded the erosion threshold, or T-value, conventional practices seemed most susceptible to erosion by wind, while the organic sites were near the threshold for erosion by water. The organic site in the east also exceeded the T-value for wind erosion.

• Soil organic matter content among farm sites generally ranked no-till>organic>conventional. A notable exception was the conventional site in the west, which despite a wheat/black fallow rotation, maintained organic matter and other soil properties similar to the alternative sites through regular use of livestock manure.

• Chemical fallow was more efficient than black fallow at moisture storage (23 vs. 5%), but also contributed to excessive soil nitrate deep in the soil profile. Increased moisture capture and retention through reduced tillage must be accompanied by intensifying the crop rotation to avoid groundwater contamination.

• The organic farms had the greatest crop diversity among all farm sites. Legumes were grown in rotation to provide nitrogen. Legumes were grown 3 out of 4 years in the east, 2 out of 4 years in the central, and 1 out of 4 years in the west region of North Dakota between 1988 and 1992 on the fields studied.

• Organic and no-till sites generally had greater numbers of soil insects than conventional sites. Among specific species of insects, greater ground beetle populations at organic sites suggest a role they may play in biologically reducing the number of weed seeds.

• No-till sites required the greatest use of pesticides, followed by conventional sites. Pesticide use also increased from west to east. Organic sites used none.

• Water-use efficiency was generally greatest at no-till sites, but depended upon the crop grown. Overall 1990/1991 mean water-use efficiencies for the conventional, no-till, and organic sites were 476, 637, and 369 pounds of above ground dry matter produced per inch of precipitation. Beyond the influence of the farming practices themselves, fallow or production of an over-wintering green manure crop were the factors which most reduced water-use efficiency as calculated.

• Yields were similar among farm sites. Both alternative farming systems produced equal or greater wheat yields then the conventional farms, with no-till often achieving the greatest annual yield.

• The total quantity of energy consumed in the conventional cropping system was reduced by 30% with no-till, and by 70% with organic farming systems. No-till practices shifted energy use from that expended for machinery and fuel to fertilizer and pesticides. Organic farms achieved their reduction through less tillage from use of over-wintering legumes, and no pesticide or fertilizer use. Comparing crop yield to the energy expended with an output:input ratio found the organic sites superior in energy efficiency at 9.0, no-till at 7.03, and conventional practices the least efficient at 5.4 .

Conclusions from this study suggest that current farming practices can be further improved, resulting in greater environmental quality and less energy use while maintaining or even improving crop yield. The key to building soil quality seemed to depend upon a regular availability of sufficient quantities of organic matter. This was accomplished through reducing tillage, use of a crop rotation which included green manure and spreading of livestock manure or other soil amendments. Water quality seemed most threatened in reduced-till systems which did not balance precipitation with crop water use. Maintenance of soil surface cover and use of a variety of crops in rotation seemed to best promote biodiversity of animal life. Beneficial surface and soil insects provided a means of binding soil nutrients within the crop rooting zone and perhaps provided a means of reducing weed seed survival.

Farmers considering adopting these alternative practices to reduce the environmental impact of their current cropping systems should also consider the possible risks which were detected in this study. Environmentally, the greatest vulnerability of the no-till system was water quality, while soil erosion was of concern with the organic system. Agronomically and economically, the no-till system was dependent upon the availability, price, and performance of pesticides and fertilizers. Conversely, the organic system was dependent upon the demand, price, and market stability for various alternative crops, such as rye, millet, and buckwheat required for crop rotation. Agricultural policy being shaped on both issues, through pesticide registration and international trade, will have a direct bearing on which alternatives will be the most attractive in the future. Over the long-term, specific innovations found among all these well-managed farms can be put to use in further developing more sustainable farming practices for North Dakota.

Farming Practices for a Sustainable Agriculture in North Dakota

Introduction and Objectives

In North Dakota agriculture is vital since it remains one of the most rural and farming dependent states in the country. Changing technologies have had a dramatic impact on farming practices, which in turn have influenced characteristics of the farm, the rural community, and the Northern Great Plains region. In response to these internal changes, and national economic, environmental, and social trends, a wide variety of farming enterprises have evolved as coping strategies over the past several decades. Today, farming in North Dakota is probably as diverse as it ever has been. Conservation tillage, no-tillage, irrigation, crops such as potatoes and sugar beets, organic farming and marketing, mixed species and rotational grazing, sheep, angora goats, buffalo, fish, and a long list of field crops have all become a part of, and are helping shape, the future of farming in North Dakota.

Economics and job opportunities drive many of the new farm ventures in North Dakota. Technology applied on the farm during the past few decades has reduced labor requirements, but in many cases, lowered net farm income potential. Adjusting to these new economic and demographic trends has resulted in new strategies to remain fiscally and socially stable well into the future through initiatives such as Vision 2000, Growing North Dakota, and others. North Dakota is now charting a future course for education, government, and critical services such as medical care.

An important component of a sustainable future for North Dakota must include the maintenance and well being of the environment. A higher proportion of land is engaged in cropping than in any other state (64%), and when combined with land grazed, farming practices have a direct impact on more than 91% of North Dakota's land on an annual basis (Dept. of Commerce, 1987). Several alternative farming practices are evolving. The environmental benefits from conservation tillage on a farm-scale have been documented (Bauer and Black, 1981). Less is known about the ecology and long-term environmental impact of other frequently mentioned alternative systems, such as no-tillage, organic farming, rotational grazing, and others.

The objectives of this study were to gather data from farms across the state which have been successfully managed using different kinds of farm management practices. The long-term impact of tillage, green manures, livestock manure, pesticides, and crop rotations were some of the features compared among farms. These ecological data on environmental impact were gathered to be viewed in combination with data already published on productivity, risk, economic returns, and social benefits from the various farming practices (Stearns et al., 1991; Jacobsen et al., 1991; Dahl et al., 1991; Sell et al., 1991). A secure future for North Dakota will be dependent upon farming systems which support all these dimensions of a sustainable agriculture.

Recognition of the Need for a More Sustainable Agriculture

Socio-Economic Barriers <u>to a Sustainable Agriculture in North Dakota</u>

Socio-economic trends evident across the US have also occurred in North Dakota. The size of individual farms has grown while the number of farmers has decreased (Fig. 1). Larger tractors, wider implements, fewer farms with livestock, and wider use of pesticides have been substituted for labor on the farm. Today, one full-time North Dakota farmer can comfortably care for nearly 1,000 cropland acres depending upon the combination of technologies employed (Stearns et al., 1991). Perhaps most discouraging to North Dakota about agriculture's current national economic trend is the steady shift of revenue away from the farm sector to the input and marketing sectors (Fig. 2). Smith (1992) clearly distinguishes farming from agriculture as it currently exists in the US. While farming includes farms and farmers (about 1.3% of the labor force), agriculture

employs over 13% of all American workers. Farming is but one sector of agriculture which also includes the input sector (suppliers of goods and services to farmers) and the marketing sector (processors, distributors, transporters and retailers of agricultural products). The shrinking market share of the farming sector has a special significance to states like North Dakota since the other sectors are yet of limited significance in the agricultural economy. North Dakota's farm sector economy and infrastructure were found limited in ability to support and encourage a greater diversity of input and market sector linkages (Sell et al., 1991).

Figure 1. Farm numbers and size from 1950 to 1989 in North Dakota. Farm numbers have been adjusted to exclude farmers who worked more than 200 days off-farm employment (ND Ag Stat., 1989).

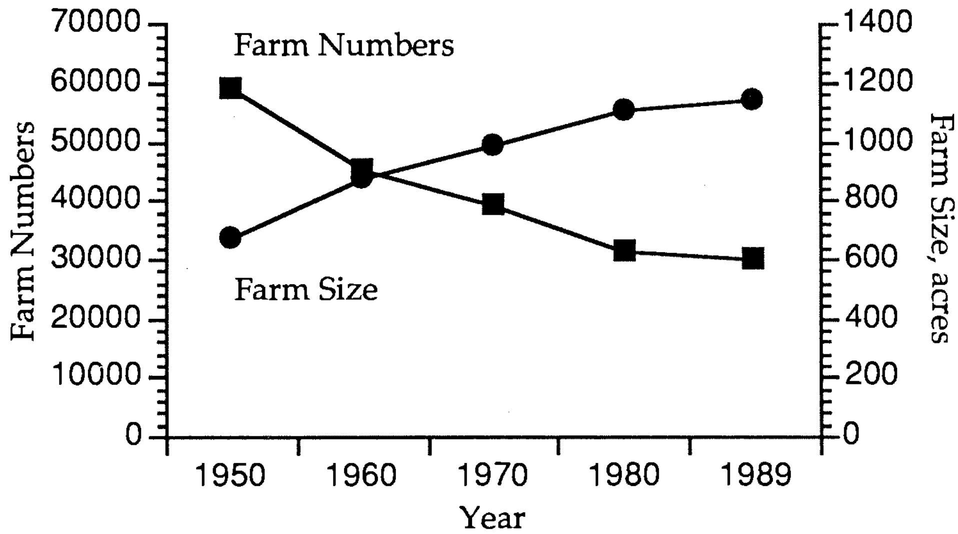
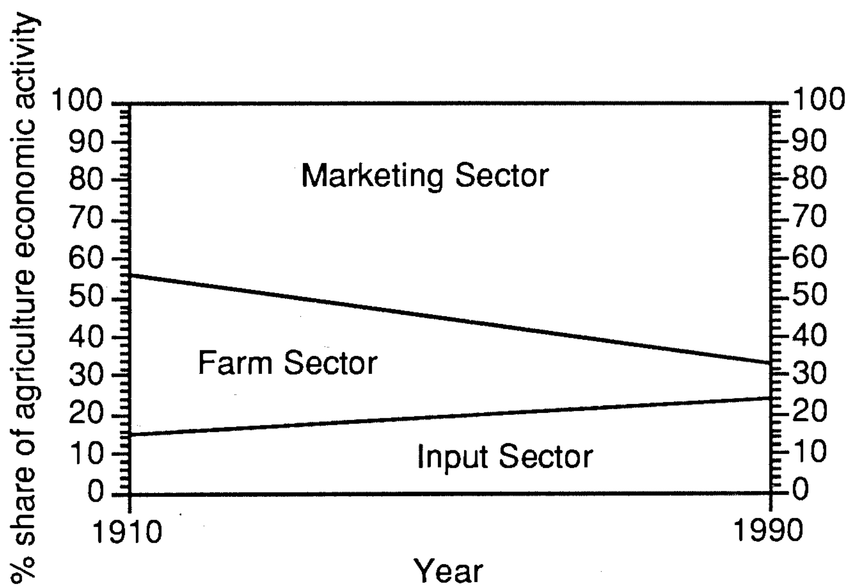


Figure 2. Relative income captured by marketing, input, and farm sectors of agriculture in the US from 1910 to 1990 (Smith, 1992).

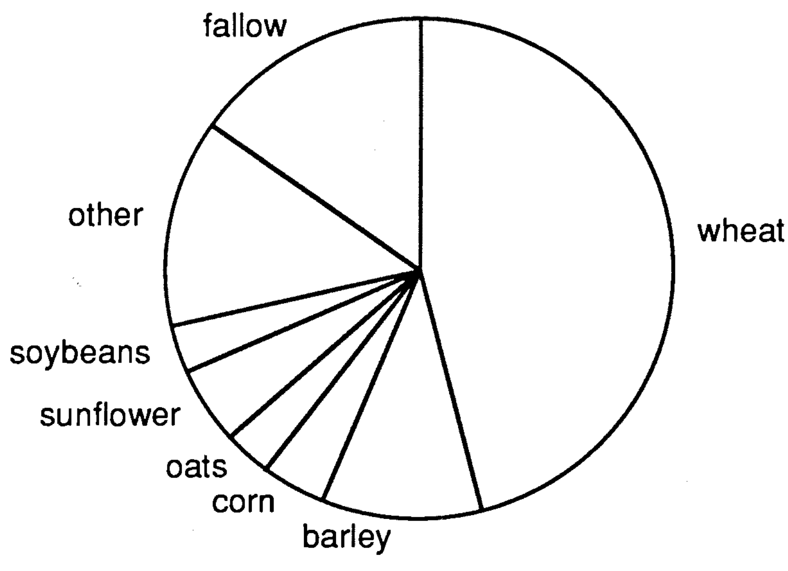


The most prevalent strategies for improving economic survival on the farm have generally followed what might be suggested by Smith's (1992) analysis: either reducing the cost of the input sector or maximizing participation and linkage with the marketing sector. Examples of

such strategies include the presence of Maximum Economic Yield (MEY) clubs across North Dakota in the late 1980's, and the success of farmer-owned processing and marketing cooperatives such as the sugarbeet industry in the Red River Valley. More recently, the start-up of a integrated durum wheat milling/pasta manufacturing farmer-owned cooperative has encouraged other groups of North Dakota farmers to discover ways of participating in the marketing sector with fish, buffalo, oilseeds, and other farm sector products.

Crop rotation has long been recognized as a valuable management practice, yet has declined in use and sophistication in recent years. Farms must be operated to remain profitable and specializing in the production of a narrow range of crops has optimized economic return. Though farm subsidies from the federal government began as a stimulus for soil conservation in the 1930's, since, they have largely served as a mechanism to maintain adequate supplies of the nation's major commodities. Arguably, this has been in the public's greater interest, but such policy also has changed farm practices, most noticeably crop rotation. Farm program crops such as wheat, barley, and corn alone account for about 70% of all planted acreage annually in North Dakota (ND Ag Stat., 1989). The allocation of land to various crops during 1992 in North Dakota is found in Figure 3. Though a surprisingly large and diverse number of field crops are adapted and can be grown in North Dakota (NDSU, 1992), few have sizable enough markets to encourage production.

Figure 3. Percent of total cropland planted to the major crops in North Dakota during 1992 (personal comm., ND ASCS, 1993).



Unlike tillage, pesticides, or other cultural practices which have products associated with them to link farmers with agriculture's input sector, creating demand for a diversity of crops to stimulate crop rotation is dependent upon agriculture's marketing sector. With market demand targeted to so few commodities, North Dakota farmers wanting to fully utilize the benefits of crop rotation have had to be self-reliant, creating their own markets by passing crops through livestock (to essentially market silage, hay, legumes, and feed grains to themselves), forming marketing cooperatives (such as the sugarbeet, durum wheat, oilseed, buffalo, and fish growers), or by linking with partners in the marketing sector to satisfy niche markets (such as producing organic and bio-dynamic foods).

While older technologies, such as tillage, have been recognized for their limitations, hidden costs in newer technologies are now being noted. Though the impact of pesticide and fertilizer use seems apparently negligible at this point, indicators are now surfacing which may point out the more vulnerable aspects of their current use in North Dakota. Annual freezing and thawing deep in the soil profile may provide a mechanism to concentrate and then flush unwanted

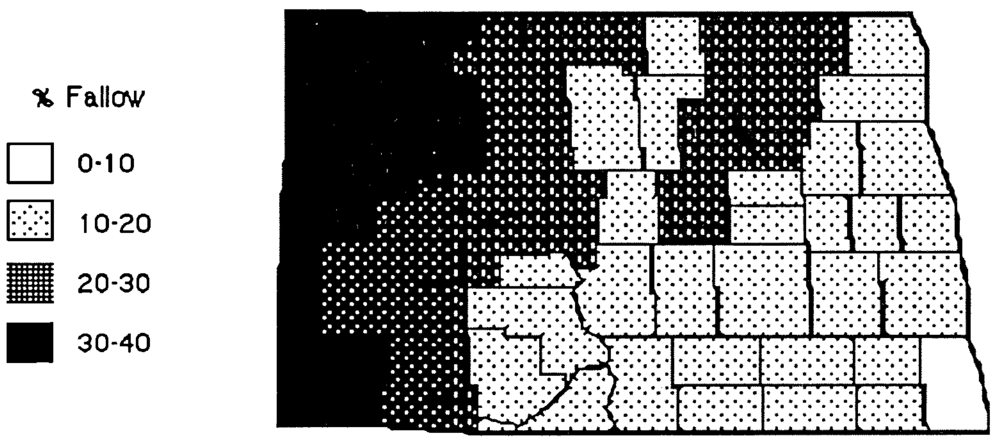
contaminants downward faster than previously thought (Schuh et al., 1993). And, though North Dakota's cool and semi-arid climate is an aid in reducing fungicide and insecticide needs, continual rotations of early spring-planted crops have made herbicides a growing necessity. With herbicides annually applied to nearly 90% of North Dakota cropland (McMullen et al., 1989), weed resistance is becoming an increasing problem among the more frequently used products. With a future of fewer and more similar herbicides possible, cultural means of weed control may again become important.

Evolution of Farming Practices
to Achieve an Ecologically Sustainable System

Evaluating farming systems for their ability to achieve environmental, rather than economic sustainability is inherently more difficult to determine since a reliable and universally understood currency (such as dollars are to an economic analysis) is yet, or may never be agreed upon. Though individual components of ecological evidence and environmental impact can be measured, how they are interpreted and dealt with largely depends upon an individual's values and beliefs (Beus et al., 1991). Environmental problems which result from agricultural practices often are ignored until symptoms of failure, such as soil loss from erosion, begin to have economic consequences. Chronic environmental degradation events often occur at rates which span several human generations (Lowdermilk, 1953).

The longest running environmental concern has been that of soil erosion (Lowdermilk, 1953). In a region of few winter annual crops, tillage is predominately done both in the spring and fall. Besides preparing a seedbed and incorporating crop residue, tillage frequency and intensity is often managed to blacken and warm the soil, which lengthens an already short season. These agronomic practices combined with frequent periods of drought result in severe wind erosion and loss of topsoil. Even when rainfall is abundant, it often falls in intense, short storms which cause severe erosion from washing on sloping lands. Another factor increasing the vulnerability of soil erosion across much of North Dakota is the frequency of fallow. Traditionally used to reduce the risk of crop failure through greater conservation of soil moisture, mineralization of nutrients, and better control of weeds, it is still practiced as frequently as once in every three years in some regions such as northeastern North Dakota despite the abundance of precipitation and use of fertilizers and pesticides (Fig. 4).

Figure 4. Percent of cropland in fallow during the 1987 growing season by county in North Dakota (Dept of Commerce, 1987).



Tillage

Changes in tillage practices in response to soil erosion were first begun in the 1930's. New technologies evolved, each increasing the amount of crop residue which could be maintained on the soil surface, thereby reducing the vulnerability to erosion. The succession of tools have included plows, disks, rod weeders, wide blade chisel sweeps, the noble blade, and most recently chemical herbicides to control weed growth while reducing tillage. With the registration of glyphosate (Roundup™) in 1976, farmers looked more seriously at adapting no-tillage practices which were being developed in the southeastern US with row crops and in the Canadian prairie provinces with small grains. North Dakota State University, recognizing the feasibility and the farmer interest in developing minimum or no-till farming systems, organized and presented a tillage seminar in four cities across North Dakota during the spring of 1977. Featuring research results, these seminars suggested that reducing tillage and continuous cropping would reduce erosion, increase soil moisture capture, reduce fuel use, and increase profit potential. They also warned that reducing tillage would limit weed control options and could lead to greater loss in yield from crop diseases.

While conservation tillage research and farmer adoption of reduced tillage systems slowly increased, the concept of no-till became an attractive goal. Research began at Mandan, Langdon, Williston, Fargo, and Minot on no-till's most urgent problems of seeding equipment for planting and chemical herbicides for weed control. Farmers began no-till on a trial and error basis citing advantages which included the reduction of soil erosion, conservation of soil moisture, lower energy requirements, lower labor costs, intensified crop rotations leading to greater profits, reduced machinery requirements, and the challenge of developing a new farming system (Manitoba-ND Zero Till Workshop, 1979). In North Dakota, no-till farming initially began in the driest (southwest) and wettest (northeast) regions. The first workshop in 1979 quickly grew into one of the single largest US/Canadian farmer organization thriving today; the Manitoba North Dakota Zero-Till Association (ManNDZTA). This farmer group hosts on-farm field tours during the summer and an educational seminar during the winter with the purpose of learning and sharing ideas on how to reduce dependency upon tillage in Northern Plains farming practices.

Conservation tillage has grown from being practiced on only 8% of the land in North Dakota during the 1984 season, to nearly 23% in 1992 (CTIC, 1992). Strict no-till has grown more slowly over the same period, reportedly used on 3.5% of the cropland acres in North Dakota during 1992 (CTIC, 1992). The reduced cost of glyphosate, since the patent has expired, and improved design in large air-seeders for small grains now makes reduced or no-till systems increasingly attractive. Regulatory pressure to meet conservation compliance through residue management by 1995, improved residue conserving tools, and farmers as skilled leaders in farming successfully using less tillage indicate that soil erosion may be significantly reduced in the future. A sustainable agriculture for North Dakota will not be possible unless farming practices are used which reduce current rates of soil erosion.

Crop Rotation

Both history and science have concluded that crop rotation (the growing of different kinds of crops in recurring succession on the same land) is beneficial to the land and to long-term crop productivity (Weir, 1926; Columella, 1941). Benefits claimed through use of well planned rotations include maintaining and building soil fertility, reducing soil erosion, reducing the build-up of disease, insect, and weed pests, spreading the farm workload, reducing the vulnerability to weather damage, reducing the reliance upon pesticides and fertilizers, and increasing net profits (Ball, 1987). Despite such desirable outcomes which seem consistent with the desire for a more sustainable agriculture, it has perhaps been the single most neglected cultural practice of the past several decades. Recent agricultural innovations have combined to inadvertently replace crop rotations with greater machinery size and capacity, fertilizers, herbicides, insecticides, fungicides, and host-plant resistant crop varieties. Crop rotation once inferred a combination of crops chosen for their ability to establish mutually supportive physical, chemical, and biological relationships within the soil. It now often means no more than not planting the same crop for two years in succession.

Organic farmers have been one of the best sources of knowledge about crop rotation, since they rely exclusively upon cultural means of providing fertility and pest control. First recognized nationally in a 1980 USDA report (USDA, 1980), organic farming gained momentum during the 1970's in response to rising energy costs of farm inputs, recognition of steady decline of soil productivity and tilth despite adequate fertility, concern for environmental degradation due to agrochemical contamination, hazards to human and animal health from pesticides, and fewer family farms and localized markets. Despite the 1980 report and others (NAS, 1989) which have suggested that farming practices, such as crop rotation, used by organic farmers could play a key role in a more sustainable agriculture, organic farming is still often viewed skeptically. No doubt, both the socio-political character of organic farming, and it's weak link to agriculture's input sector have left it out of step with traditional production agriculture support groups. Interestingly, the current excitement with 'value-added' agriculture and building stronger links between the production and marketing sectors of agriculture (USDA, 1992) have long been a vital part of organic farming's economic strategy.

Today, North Dakota is the nation's leading producer of organic grains and oilseeds. The state's continental climate provides an environment conducive to cultural control of pests and maintenance of fertility with cold winters, short summers, low humidity, prairie soils, and a wide diversity of crop plants with which to plan rotations. Farmers interested in organic farming first organized in the fall of 1978 and formed a group called the North Dakota Natural Farmers. This organization was later changed to the Northern Plains Sustainable Agriculture Society (NPSAS). The NPSAS provides information on how to reduce dependency upon agrichemicals through switching to more self-reliant crop rotations (Kirschenmann, 1988). It also seeks stronger marketing sector linkages for organic grains and minor crops used in rotation such as buckwheat, winter rye, and millet.

New Farming Systems from Converging Goals?

Improved tillage and crop rotations are critical for a sustainable agriculture, and it's no coincidence they each have a North Dakota farmer organization primarily concerned with their betterment. What sets the ManNDZTA and NPSAS apart from other farmer organizations is their focus on farming practices rather than single commodities, single products, marketing, insurance, business, or political strength. These two organizations have other similarities too, both forming in the late 1970's, environmentally concerned, and farmer-driven both in organization and innovation. How they differ is in their approach.

The ManNDZTA views soil erosion as the largest threat to sustainability, thus has sought ways to reduce tillage. Recognizing that new tools were going to be needed to achieve soil conservation, they developed allies within agriculture's input sector. Their success is evident in both herbicides and farm equipment now available. Two North Dakota input sector companies (Haybuster and Concord) are industry leaders in developing reduced tillage planting equipment for the Great Plains. A host of other farmer innovations are also now commercially available including straw and chaff spreaders, sprayers, and marking systems, all which have been critical to the success of reduced tillage farming practices.

Of greater concern to the NPSAS has been the threat of agrochemical contamination and dependency, a loss of soil productivity despite attempts at fertilization, and a growing trend of fewer family farms and markets. Assessing these concerns, a two-fold strategy was developed. First, many of the environmental threats to sustainability stemmed from farming practices reliant upon agrichemicals. A process of substituting purchased inputs with ecological processes inherent in innovative crop rotations was developed. This allowed these farmers to disengage from a large portion of agriculture's input sector. Secondly, to provide the markets for the crops needed in rotation, they developed relationships with segments of the marketing sector sympathetic to their concerns. Their success is evident in the growing organic food industry and mimics of their marketing strategy, such as Pioneer's Better Life™ grains grown without pesticides.

These very different approaches to a more sustainable agriculture for North Dakota are now recognizing their complimentary accomplishments. Organic farmers have long needed an

agricultural input sector more sensitive to the needs of non-chemical pest control. Only recently have innovations in rotary hoes and the value of beneficial insects and diseases been given broad consideration. Likewise, it has only been recently that partnering with the marketing sector has been attempted among traditional non-organic grains such as durum wheat, or to create markets for alternative crops unique in their ability to naturally resist pests and conserve the soil, such as crambe.

This study was conducted to search for the most sustainable agriculture practices of crop production being practiced. It took place on farms from across North Dakota, and included members of the ManNDZTA, NPSAS, and others unaffiliated with these groups.

A Comparative Study of North Dakota Farming Practices

Though an experimental approach (such as agricultural experiment station trials) has long been used to identify improved methods of tillage, rotation, or pest management in isolation, little if any data currently exist to compare the relative impact of these practices as they are actually employed on the farm. Though it is difficult to categorize farms and farmers, three farm management approaches were chosen for comparison in North Dakota based upon the length of time and success of farmer-driven organizations promoting their adoption. All had been successfully using their current management practices for more than ten years. Similar data was also gathered from prairie sites during the course of the study. The ecosystems compared included the following:

Identification	Description
Prairie	Sites stable successionally with native or naturalized vegetation
Conventional	farms successful using practices which are predominant in region
No-till	farms making extensive use of conservation (or no) tillage
Organic	farms making extensive use of crop rotation to substitute for little (or no) pesticide or fertilizer inputs

Since North Dakota has three dominate eco-regions, sites of each type were carefully chosen in each region which shared similar soils (Fig. 5). Though general data were taken from each farm, one specific site (field) per farm was chosen with soil types which matched other sites within a region. These twelve sites were visited bi-weekly throughout the 1990 and 1991 growing seasons to measure environmental impact physically on the soil, chemically on soil nutrient use and efficiency, and biologically both above and below ground. Success of these farms measured by productivity or environmental impact did not necessarily insure equal economic success. Companion studies lead by Dave Watt in the Agricultural Economics Dept. were conducted to compare these farms for interaction with their economic and social communities. Additional methodological details are found in the methods section.

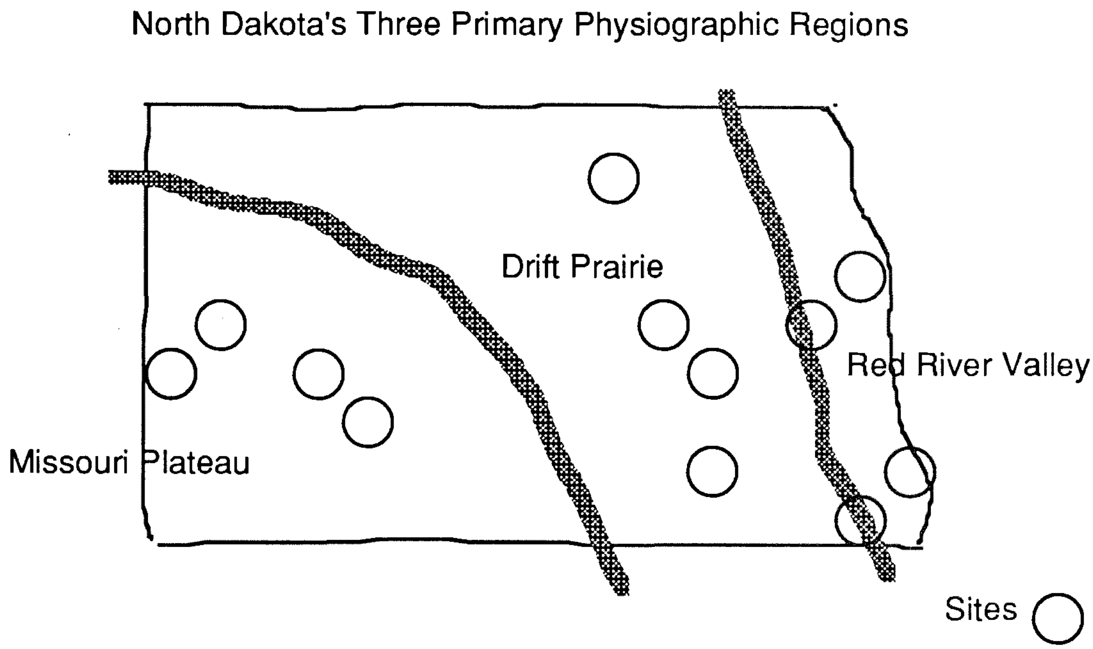
The Overall Impact of Farming Practices

Since the sites were not directly adjacent to one another, differences in precipitation and other weather variables occurred. Data gathered during the two years of this study thus concentrated on those factors which change more slowly, are less sensitive to the immediate conditions, and tend to be more stable.

Disturbances occur in all ecosystems. Naturally occurring large scale disturbances such as fire on the prairie and small scale disturbances such as gopher mounds create open areas in the tightly knit matrix of prairie vegetation composed primarily of perennial species (Collins and Barber 1985; Steuter et al. 1990; Biondini et al. 1989). The small open areas are initially revegetated by annual species of forbs and grasses (Collins 1987; Scudder et al. 1989), giving the prairie landscape its characteristic "patchy" appearance. Historical accounts and research on tree ring measurements have shown fire frequency on native prairie to have occurred at irregular intervals of two to seven years (Bragg 1984). Agroecosystems are subjected to disturbances each year

through tillage, planting, harvest and other means of managing annual crops. The farm sites greatly differed in crop rotation and frequency of disturbance (Table 1).

Figure 5. Map of North Dakota with geographic regions and sites identified for ecological study during 1990 and 1991.



Tillage

Though organic farming practices are generally thought of as tillage intensive, conventional sites had the highest tillage frequency in both the east and central regions and the highest susceptibility to wind erosion. The central and west organic sites with combined factors of sloping topography and tillage practices were more susceptible to water erosion (Table 1). Organic sites also had a greater frequency of legumes in the rotation.

Both tillage frequency and severity are important because of physical impact on many soil properties. Among the physical properties compared(Table 2), both bulk density and organic matter content were reflective of each site's history of tillage management. The east and central no-till were comparable to the prairie in soil texture but the prairie was distinct from all the agroecosystems in its granular soil structure. Though not always statistically different, the highest bulk densities in each region were found on the conventional sites, the lowest on the prairies.

Organic matter on the prairie sites were significantly greater ($p= <0.05$) than all agroecosystems across the state. It was reported twenty years ago (Haas, 1974) that conventional agricultural practices had reduced soil organic matter levels by about 50%. In comparing the prairie to the conventional sites across North Dakota, these practices have reduced organic matter levels by 71% in the east, 57% in the central, and 27% in the west region. Among the agroecosystems, no-till tended to have the greatest organic matter, followed by the organic and conventional sites. Thicker topsoil on the east and central no-till sites was attributed to greater organic matter and biological soil forming factors. Though not always statistically significant, the organic matter among sites within a region compared similarly except for the west region. The greater than expected organic matter content at the west conventional site was probably due to the regular use of livestock manure as a soil amendment (Table 2). Other soil physical characteristics of the west agroecosystems were very similar despite the differences in management. The west region of North Dakota is semi arid as compared to sub-humid region in the east and central portion of the state.

The impact of farming practices on soil aggregate size varied by region. In the east region, the prairie and no-till sites had a significantly greater proportion of the largest aggregates as compared with both the conventional and organic sites ($p = <0.05$). The conventional site also had the greatest proportion of smaller aggregates ($p = <0.05$). Though the trend for prairie, no-till, and organic sites having the largest soil aggregates continued in the central region, fewer statistically significant differences were found. Sites were most similar in the west region (Fig. 6). Soil aggregates larger than 0.85 mm in diameter are generally considered less erodible than smaller aggregates. Both the no-till and organic farming practices seemed to have resulted in soil which is less vulnerable to wind erosion in central and eastern North Dakota.

Farming practices, such as tillage, have been found to influence the biology of the soil. Under conventional tillage systems, bacterial populations are thought to be higher than fungal populations. Bacterial populations are subject to higher rates of turnover and subsequent carbon loss from the system. Conversely, under limited or no-tillage systems, soil fungal populations have been found more important, particularly in surface soils. This is significant because the interconnected strand-like growth pattern of fungal hyphae enhance the translocation of soil nutrients through the soil profile. Indirect evidence of increased fungal activity among the no-till sites was found because of the high numbers of springtails (Collembola) found. Springtails graze on fungi, and are reported to be drought tolerant, have a high metabolic rate and high locomotive activity.

No-till systems require fewer trips across the field replacing disks, chisel plows and harrows with a drill capable of opening the untilled soil, depositing seed and banding fertilizer. No-till systems used the least amount of machinery-fuel use energy equivalents (kcal a^{-1}) in this study followed by organic systems and then conventional systems (Table 3).

The wet aggregate stability, or the ability for the soil aggregates to resist breakdown, is another important characteristic in determining how vulnerable a soil is to erosion. Sites with more tillage, such as the conventional and organic, had lower aggregate stability over the two years of sampling in the eastern and central regions. In the west, the prairie site had more stable aggregates than the agroecosystems. Despite a wheat/black fallow rotation at the west conventional site, the regular use of livestock manure as a soil amendment had a greater positive impact on soil quality factors than expected.

In general, those farm sites which either reduced organic matter loss through reduced tillage, or increased organic matter returned to the soil through green or livestock manures had soil quality factors which came closest to the prairie sites.

Table 1. Crop rotation and tillage/harvest practices by site from 1988-1991.

Year	Prairie rotation	Prairie tillage	Conventional rotation	Conventional tillage	No-till rotation	No-till tillage	Organic rotation	Organic tillage
East Region								
1988	grass/ forb	hayed	beans	harrow/seed/ 2x harrow/ harvest/disk/ anhydrous	beans	seed/ harrow/ harvest	beans	f. cult./harrow seed/2 x r. hoe/ cult./harvest/ disk/ f. cult.
1989	grass/ forb	hayed	sm grain	harrow/seed/ harrow/ harvest/c.plow/ disk/c.plow	sm grain harvest	seed/ harrow/	sm grain/ alfalfa	f. cult/seed/ harvest
1990	grass/ forb	hayed	beans	harrow/seed/ 2x harrow/ harvest/disk	corn	seed/ harrow/ harvest	alfalfa	hay
1991	grass/ forb	hayed	sm grain	anhydrous/ harrow/seed/ harrow/harvest c.plow/disk/ c.plow	beans harvest	seed/ harrow/	alfalfa	harvest/plow
mean tillage events per year		0		4.5		1		2.3
legume frequency %				50		33		75
*erosion	W 0.1	WD 0.0	W 0.2	WD 11.1	W 0.6	WD 0.1	W 0.1	WD 9.1
*T value	W 4.0	WD 4.0	W 4.0	WD 4.0	W 5.0	WD 5.0	W 5.0	WD 5.0
Central Region								
1988	grass/ forb	grazed	sunflower	2x f. cult./seed r. hoe/cult./ harvest/disk	sm grain	seed /harvest	w. rye	harvest
1989	grass/ forb	grazed	sm grain	disk/2x f. cult./ seed/harvest/ disk	sm grain	seed /harvest	b. wheat/ s. clover	f. cult/seed/ harvest
1990	grass/ forb	none	sm grain	seed/harrow/ harvest/c. plow	sm grain	seed /harvest	s.clover/ fallow	disk/ 4x f. cult
1991	grass/ forb	none	sunflower	harrow/c. plow f. cult/seed/ r. hoe/cult/ harvest	sunflower	harrow seed/ harvest	beans	f.. cult/seed/ 2xr. hoe/cult/ harvest
mean tillage events per year		0		4.0		0		2.2
legume frequency %				0		0		50
*erosion	W trace	WD trace	W 0.7	WD 3.4	W 0.5	WD 0.0	W 4.0	WD 0.0
*T value	W 5.0	WD 5.0	W 5.0	WD 5.0	W 5.0	WD 5.0	W 5.0	WD 5.0
West Region								
1988	grass/ forb	grazed	fallow	3x f. cult with rod weeder	fallow	none	corn/ s.clover	disk/f. cult/seed 2x cult/harvest
1989	grass/ forb	grazed	sm grain	f. cult/seed/ harvest	sm grain	seed/ harvest/ harrow	s.clover/ fallow	disk/ 2x rod weeder
1990	grass/ forb	grazed	fallow	3x f. cult with rod weeder	sm grain	seed/ harvest/ harrow	sm grain	2x f. cult/seed/ harvest
1991	grass/ forb	grazed	sm grain	f. cult/seed/ harvest	fallow	none	sm grain	disk/f. cult/ seed/harvest
mean tillage events per year		0		2		.5		2.8
legume frequency %				0		0		25
*erosion	W trace	WD trace	W 1.9	WD 0.5	W trace	WD trace	W 4.1	WD 2.3
*T value	W 4.0	WD 4.0	W 4.0	WD 4.0	W 4.0	WD 4.0	W 4.0	WD 4.0

*erosion = erosion tons a^{-1}; W = via water; WD = via wind

* T value = T value tons a^{-1}

Table 2. Mean soil quality characteristics by site during 1990 and 1991.

Site Identification

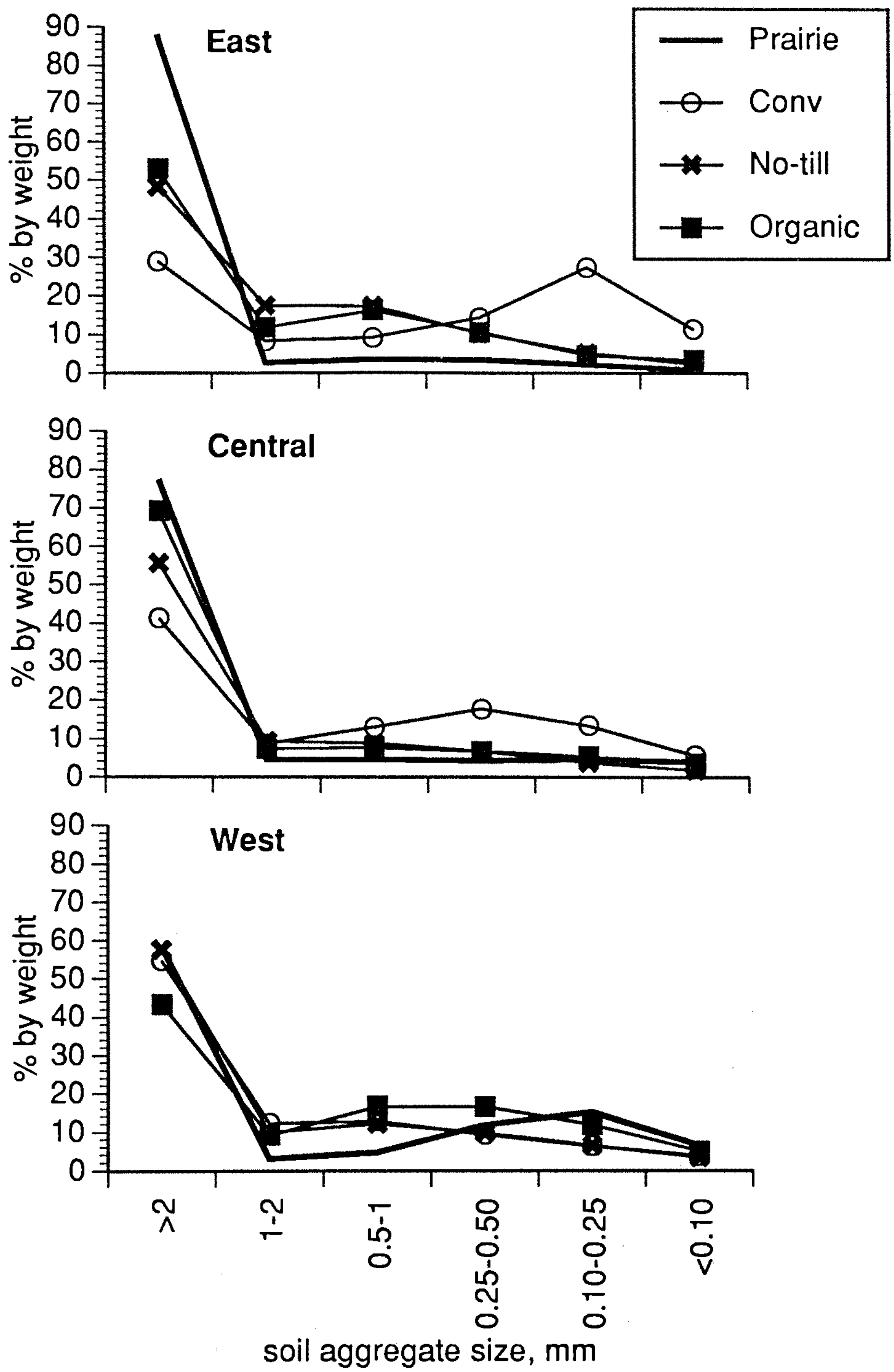
Soil Property	East region				Central region				West region			
	Prairie	Conv.	No-till	Organic	Prairie	Conv.	No-till	Organic	Prairie	Conv.	No-till	Organic
Texture	clay loam	clay	silt loam	silt c.	loam	c.lay	loam	c. loam	c. loam	c. loam	silt c.	loam
Structure	gran-ular	blocky to gran.	blocky	blocky to gran.	gran-ular	blocky to gran.	blocky	blocky to gran.	blocky to gran.	blocky to gran.	blocky to gran.	blocky to gran.
Depth A horizon (cm)	20	47.5	32.5	37.5	20	22.5	45.	42.5	17.5	15.0	15.0	15.0
*Bulk density ((0-15 cm(g cm^{-3}))	0.62	1.04	0.88	1.02	0.98	1.13	0.90	0.95	0.99	1.17	1.07	1.02
Total NO_3-N (lb a^{-1} 0-4 ft))	27.7	67.0	101.9	32.1	29.3	103.6	60.9	85.7	25.4	114.90	218.7	55.4
Total P (lb a^{-1} 0- 6 in)	16.0	20.0	15.0	9.0	12.0	21.0	30.8	19.5	10.3	63.0	18.3	28.5
pH	7.8	8.0	7.6	8.0	7.1	7.23	7.0	7.5	7.5	6.92	7.9	7.4
Organic matter (%, 0-15cm)	8.7	2.78	6.14	4.64	5.98	3.09	5.33	4.16	4.29	3.06	3.48	2.82
Light fraction OM (mg kg^{-1}, 0-15cm)	12623	1320	635	1015	7588	3048	5128	4190	10130	2158	3262	3295
Wet aggregate stability (%, 0-6 cm)	93	81	94	81	96	84	95	92	95	79	79	79

Bulk densities based on assumed particle density of 2.65 g cm^2

Table 3. Mean annual energy use for machinery and fuel among the nine sites during 1990 and 1991.

Region	Farm Site: Conventional	No-till	Organic
		kcal a^{-1}	
East	543,591	181,502	164,915
Central	466,492	238,745	376,050
West	433,537	163,302	325,172

Figure 6. Distribution of dry soil aggregate sizes by weight among six categories for each region and site.



Rotation

Fallow is used across North Dakota as a rotational tool (Fig. 4) and occurred during this study on the central organic site and the west conventional and no-till sites. The organic site used the period to grow sweetclover as a green manure, which resulted in 16.8% of the precipitation being consumed to produce 3345 lbs per acre of total dry matter biomass, or 200 lbs per acre inch of water use. The conventional site had a 5% efficiency in water conservation with no measurable biomass production, and the no-till site was 23% efficient in water storage using chemical fallow without tillage. The use of these various fallow practices, legume (green), tilled (black), and chemical (brown) are currently being studied for their impact in the central and northern Great Plains (Gardner et al., 1992).

The rotational sequence was generally the shortest at the conventional, and longest at the organic sites (Table 1). A sequence of diverse crops was used on the organic sites to provide soil fertility through inclusion of legumes, and avoid pest problems by alternating crops with similar characteristics. The botany, growth habit, and temperature adaptation of crops were specifically sequenced such as the spring wheat/winter rye/buckwheat undersown with sweetclover/sweetclover green fallow/dry edible bean rotation used at the organic site in the central part of the state. The frequency of legumes in rotation at the organic sites ranged from 75% in the east to 25% in the west. Both the conventional and no-till farm in the east also utilized legumes in rotation. Crop rotation options were less evident in the west because of fewer adapted and economical crops to grow.

One of the more striking differences among sites which seemed linked to crop diversity was with insects which inhabit the soil surface. Pitfall traps were used to capture these insects during their most active period, which usually occurs at night. Though the data were highly influenced by the crop, the general trend found for total numbers of insects trapped was organic>no-till>conventional>prairie. Closer examination of the data reveal that what the prairie lacked in numbers, it made up for in diversity of species. Other consistent trends were greater numbers of crickets and grasshoppers on the no-till and organic sites as compared to prairie or conventional sites. Biodiversity in plants seemed to encourage biodiversity in animal life.

Innovative crop rotations require additional planning, management skill, and markets to accommodate the increased complexity and diversity of crops grown. Many of the crops included in these rotations have specialized and limited markets. Thus, not only are they frequently unprofitable to sell, but should significantly greater production occur without an equal increase in demand, markets which currently exist may worsen.

Maintaining Soil Fertility

The prairie ecosystem that once covered the central United States was a closed system where nutrients were cycled through the processes of death and mineralization. Vegetation harvested by consumers in this natural ecosystem were returned to the prairie via manure and carcass decay. Natural ecosystems, such as the prairie sites, have a distinct seasonal trend in the availability of mineral nitrogen (N) which peaks in spring and autumn. The balance of the season consists of transient concentrations of mineral N followed by a low supply. N-assimilation enzymes show similar seasonal trends. The control of the supply of these enzymes is a method by which plant species adapt to a fluctuating supply of N (Haynes, 1986). Annual planting and harvesting of the primary producers in an agroecosystem depletes soil nutrients; one factor causing an agroecosystem to 'run down' unless subsidized with nutrients.

The living fraction of the soil consists of numerous species of micro-, meso-, and macro-flora and fauna. The interactions of the soil biotic components with the abiotic components characterize an environment suitable for plant growth. Three types of soil fauna were quantified for this study: microbes (bacteria), mites, and springtails. The population estimates of these soil fauna demonstrate patterns of high concentrations followed by low numbers (see site descriptions in appendix). Studies have shown that the contribution of these soil fauna could be 10-40% of the total net nitrogen mineralized depending upon assimilation efficiency of the crop for N (Verhoef and Brussaard, 1990; Lagerlof and Andren, 1988; Boles, 1988; Holland and Delting, 1990).

The conventional and no-till agroecosystems practiced annual fall soil testing to determine fertilizer requirements. The amount applied was based on the results of the test, a yield goal, and the farmer's experience. Fertilizer N input/outputs, N-use efficiency, and unaccounted for N, or 'lost' as determined by soil nitrate testing, are found in Table 5. Legumes, in association with certain bacteria have the ability to extract N from the atmosphere. This atmospheric dinitrogen fixation process is a vital factor in most natural ecosystems and was the principal supply of nitrogen among the prairie and organic sites. Legumes were inserted into the rotation more frequently as precipitation increased from west to east to supply the greater N needs of higher productivity.

Mean N additions compared on a regional basis were central>west>east. Nitrogen removed with the crop and N use efficiency were highest in the east>central>west. This corresponds to findings in soil organic matter reductions in comparing farm to prairie sites. Nitrogen unaccounted for was greatest in the west>east>central. Very little N was unaccounted for in the central region. Some of the unaccounted N is believed to be tied up in the organic matter and soil biota in the autumn to be released for use in the spring. Autumn soil tests may not reveal the true status of N at the time of planting. Crop yield at organic sites, for example, far exceeded that which was predicted through common soil testing procedures.

The combination of tillage and rotation was found important in determining the appropriate fertilizer levels and soil sampling depths. Reduced tillage at the west no-till site increased water infiltration and was not accompanied with an increase in water demand through longer season, deeper rooted, or more consumptive crops. This resulted in soil water and soil nitrate nitrogen loss beyond the crop rooting zone (Fig. 7). With fewer crop options and greater yield variability, it seemed more difficult to balance soil water supplies with crop need in the west than in the east.

The energy required to industrially fix atmospheric nitrogen makes nitrogen fertilizer one of the most energy expensive inputs used in North Dakota farming systems. The two year mean energy equivalents contained in the fertilizer applied are listed in Table 6.

Figure 7. Soil nitrate nitrogen concentration within the soil profile during the spring of 1990 among sites in the east and west regions of North Dakota.

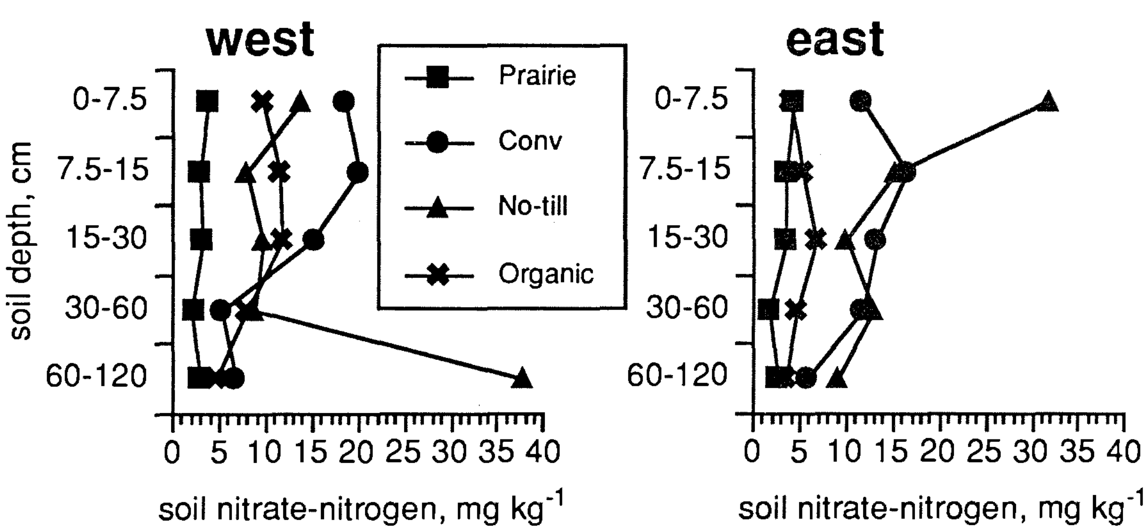


Table 5. Soil nitrogen added as fertilizer, undetected as soil nitrate by soil test, dry matter production efficiency, and removed during 1990 and 1991 by site.

	Fertilizer N added			N 'lost'			N-Use Efficiency			N removed by crop		
	1990	1991	Mean	1990	1991	Mean	1990	1991	Mean	1990	1991	Mean
	lb a^{-1}			lb a^{-1}			lb lb N^{-1}			lb a^{-1}		
East Region												
prairie	0	0	0	0	1	0.5	131	3010	1570	14a	23a	18.5
conventional	4.4	55.5	30.0	87	0	43.5	31	10023	5027	75b	58b	66.5
no-till	51.0	10	30.5	179	0	89.5	99	11705	5902	61b	225c	143.0
organic	0	0	0	0	0	0	68	1120	594	71b	1d	36.0
2 year region mean			15.1			33.3			3273			66.0
Central Region												
prairie	0	0	0	16	0	8	164	4329	2247	na	na	na
conventional	81.4	45	63.2	78	0	39	80	201	141	69a	49a	59.0
no-till	6.5	18	12.3	50	0	25	73	145	109	35b	78ab	56.5
organic	*0	0	0	0	0	0	*3345	461	1903	*0	93b	46.5
2 year region mean			18.8			18.0			1100			54.0
West Region												
prairie	0	0	0	38	47	42.5	31	29	30	na	na	0
conventional	*100	8.8	54.0	*64	0	32.0	*0	264	132	*0	58a	29.0
no-till	32	*0	16.0	183	*94	138	17	*0	9	28a	*0	14.0
organic	0	0	0	0	24	12	162	69	116	136b	27b	81.5
2 year region mean			17.6			56.3			71.5			41.5

N lost= (spring soil nitrate-N + inputs) - (crop N + fall soil nitrate-N)
N-use efficiency=dry matter produced/(spring soil nitrate-N + inputs) - (fall soil nitrate-N)
Numbers followed by different letters within a region's column are significantly different ($p<0.05$)
* denotes fallow

Table 6. Mean annual energy equivalent for applied fertilizer among the nine farm sites during 1990 and 1991.

	Farm Site		
Region	Conventional	No-till	Organic
		kcal a^{-1}	
East	431,328	722,482	0
Central	722,400	256,020	0
West	79,425	254,600	0

Pesticide Use

No-till and conventional farms used various combinations of pesticides to control pests with greater use occurring the farther east the farm was located (Table 7). No-till sites required a greater diversity of products and more frequent applications, thus consuming more energy for pesticides than conventional sites (Table 8). Herbicides accounted for most of the pesticides applied.

None of the weedy species that occurred in the agroecosystems were present on the prairie sites. The most noticeable difference in weed problems among farms were perennial weeds on the organic farms, particularly field bindweed at the western site. Otherwise, weeds were not limiting crop production at any of the sites. Weeds were managed on the organic farms by a combination of crop rotation and tillage practices. Sequences were specifically chosen to include crops with different planting dates and competitive characteristics to follow one another, such as the rotation used at the central organic site. The west organic site had two successive years of oats, but based upon past cropping history, this was an exception in response to market demand.

Ground beetles were found in the greatest numbers among agroecosystems, especially the organic sites. Many of the species found at these sites are known weed seed feeders which could help explain apparent differences in weed seed fate between organic and conventionally managed farms.

Table 7. Crops planted and pesticides applied on conventional and no-till sites during 1990 and 1991. No pesticides were applied to prairie or organic sites.

	Conventional	No-Till
East Region		
1990 Crop	navy beans	corn
herbicides	trifluralin	cyanazine/dicamba/spot glyphosate
insecticides	chlorpyrifos	thiabendazole/esfenvalerate
fungicides	captan+streptomycen	maneb
1991 Crop	barley	soybeans
herbicides	MCP ester	glyphosate+2,4D/fenoxaprop+thifensulfuron + crop oil/methyl parathion
Central Region		
1990 Crop	wheat	wheat
herbicides	MCPA	spot glyphosate+dicambe/glyphosate+ 2,4D/metsulfuron/spot imazamethabenz/ tribenuron/spot tribenuron/2,4D
insecticides	thiabendazole	-
fungicides	maneb	carboxin
1991 Crop	sunflower	sunflower
herbicides	trifluralin	pendimethalin/spot glyphosate
insecticides	-	dimethoate/m. parathion
fungicides	metalaxyl	-
West Region		
1990 Crop	fallow	wheat
herbicides	-	triallate/glyphosate+2,4D ester/ tribenuron+2,4D ester
1991 Crop	wheat	fallow
herbicides	2,4D	glyphosate+2,4D ester/dicamba

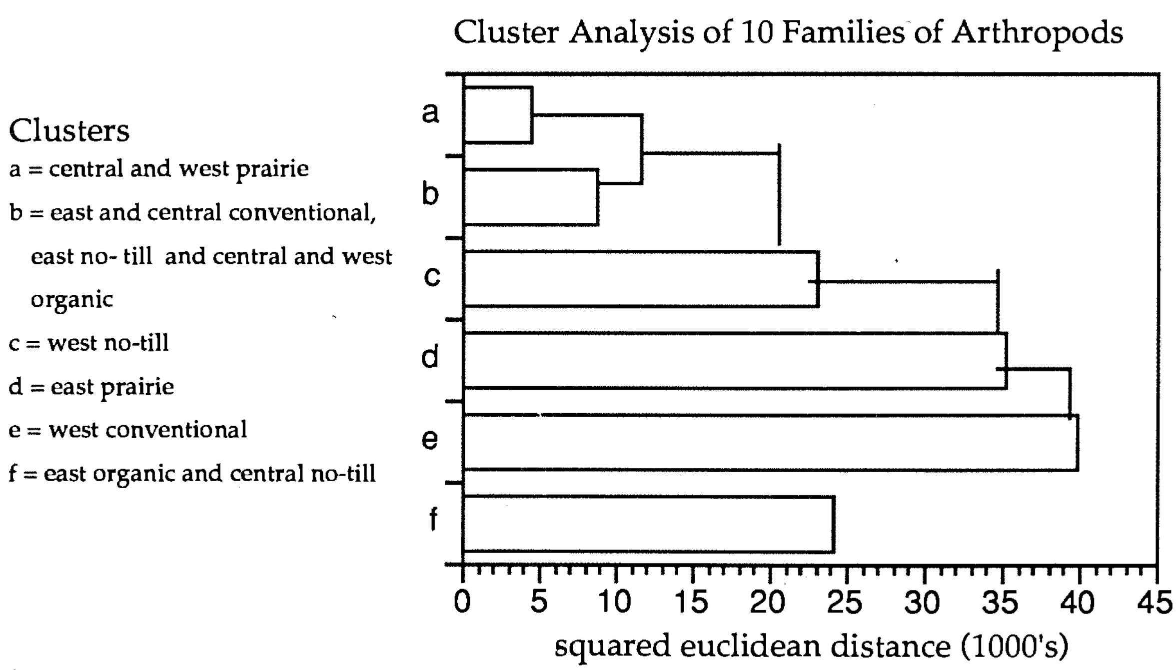
Table 8. Mean annual energy equivalent for applied pesticides among the nine sites during 1990 and 1991.

	Farm Site		
Region	Conventional	No-till	Organic
		Kcal a^{-1}	
East	91,362	268,973	0
Central	24,253	102,288	0
West	6050	45,482	0

There is increasing evidence that pesticides produce effects beyond the target pest population by creating secondary pest, resistance, and water quality problems (Harper, 1989). Farmers in Europe are testing strategies to reduce pesticide applications. In England for example, farmers began a system of conservation headlands on their grain fields where no herbicides, insecticides, or fungicides were used. The intention was to provide better habitat for game birds. Studies of these acres of weedy narrow bands indicate a side benefit of increased numbers of predatory insects and a decrease in the frequency and size of cereal aphid outbreaks (Chiverton and Sotherton, 1991).

The site descriptions in this study show data of predator/herbivore relationships for each ecosystem. The principal components of the soil arthropods collected from the pitfall traps and soil extractions were determined. A cluster analysis of 10 arthropods--two spider families, 8 predator families, one family of Collembola, and one subgroup of mites was determined. Though inconclusive, these families of soil insects seemed more related to tillage intensity than pesticides applied. The 12 sites clustered into 4 groups significantly different at $P<0.01$, (Fig. 8). The processes of infochemicals, phytotoxicity, alleopathy and autotoxicity as they relate to agricultural systems are not well documented and perhaps could be managed if better understood.

Figure 8. Ecosystems compared on the basis of arthropod populations collected from pitfall traps and soil extractions. Systems paired together are similar.



Productivity

Factors affecting productivity include precipitation, temperature, choice of crop, farm management practices, nutrient use efficiency and the interaction of these and many other variables. Crop production in North Dakota is most frequently limited by a lack of sufficient rainfall. Farm practices that influence water capture, storage, and use are thus important criteria which usually determine productivity. Water-use efficiency comparisons were based on the amount of total dry matter from above ground plant material. This is a relevant comparison for annual plants, but in the case of biennial and perennial plants on the prairie, or alfalfa and sweetclover on the organic sites, it does not include a significant portion of the plant; the roots (Table 10). No-till generally resulted in the greatest water us efficiency. Exceptions were the west no-till site which had a hail storm reducing dry matter production during the 1990 crop year.

Unlike experimental side-by-side plots where crop yields among treatments can accurately be obtained, use of the on-farm data for yield comparisons is less useful. Though the sites shared similar soil types and were matched for farm size and labor, they were widely distributed within their ecoregion of the state (Fig. 5). Large distances between sites resulted in wide variations in weather, and crop yields recorded were reflective of those local conditions (Table 10). Long term wheat yield data filed with the ASCS office revealed little difference among farms within a region, with the no-till farms generally having the highest proven yields.

Energy use calculations were determined for each of the agroecosystems as were the energy outputs estimated from the crop production (Table 9). The ratio of outputs/inputs were greatest for the organic system followed by the no-till and conventional in the east and west. No-till farms shifted energy expended on machinery and fuel for use on pesticides and fertilizers. Comparing agroecosystems in this study across North Dakota, the central no-till system was the single farm with the most favorable ratio of outputs to inputs.

Table 9. Energy output/input ratios among the nine farms during 1990 and 1991.

	Farm Identification								
	East region			Central region			West region		
	Conv.	No-till	Organic	Conv.	No-till	Organic	Conv.	No-till	Organic
	energy output/energy input								
1990	6.62	6.10	10.19	5.92	9.80	3.39	0	5.44	18.71
1991	6.61	8.17	8.48	8.67	12.67	9.75	4.58	0	3.49
mean	6.61	7.14	9.34	7.29	11.24	6.57	2.29	2.72	11.10

Table 10. Total dry matter (DM) production, total water (W) use, water-use efficiency and proven wheat yield among sites in 1990 and 1991.

Region	Prairie	Site: Conventional	No-till	Organic
East				
1990 Crop	grass/forb	navy beans	corn	alfalfa hay
Total DM, lb a^{-1}	1966a	5012a	16186b	3332a
Percent removed (harvest)	75	37	22	73
Farmer field est. yield	na	1082 lb a^{-1}	105 bu a^{-1}	2400lb a^{-1}
ASCS proven wheat yield	na	42 bu a^{-1}	33 bu a^{-1}	46 bu a^{-1}
Total W use, in. a^{-1}	16.2	11.3	13.2	13.5
W Use Efficiency, lb DM $inch^{-1}$	121.4	443.5	1226.2	246.8
1991 Crop	grass/forb	barley	soybeans	alfalfa seed
Total DM, lb a^{-1}	3010a	10023b	11705	2239a
Percent removed (harvest)	67	26	34	1
Farmer field est. yield	na	54 bu a^{-1}	40 bu a^{-1}	12.5 lb a^{-1}
Total W use, in. a^{-1}	20.5	22.7	13.6	15.9
W Use Efficiency, lb DM $inch^{-1}$	146.8	441.5	860.7	140.8
Central				
1990 Crop	grass/forb	wheat	wheat	s clover
Total DM, lb a^{-1}	2620a	11545c	6690b	3345ab
Percent removed (harvest)	na	27	28	na
Farmer field est. yield	na	50.6 bu a^{-1}	36.7 bu a^{-1}	na
ASCS proven wheat yield	na	25 bu a^{-1}	33.bu a^{-1}	26 bu a^{-1}
Total W use, in. a^{-1}	19.3	16.0	9.3	16.7
W Use Efficiency, lb DM $inch^{-1}$	135.8	721.6	719.4	200.3
1991 Crop	grass/forb	sunflower	sunflower	soybeans
Total DM, lb a^{-1}	4329a	6831ab	8266b	6450ab
Percent removed (harvest)	na	24	29	25
Farmer field est. yield	na	1665 lb a^{-1}	800 lb a^{-1}	32 bu a^{-1}
Total W use, in. a^{-1}	15.4	21.2	17.0	13.0
W Use Efficiency, lb DM $inch^{-1}$	281.1	322.2	486.2	496.2
West				
1990 Crop	grass/forb	fallow	wheat	oats
Total DM, lb a^{-1}	1195a	0	3609b	10691c
Percent removed (harvest)	na	na	26	40
Farmer field est. yield	na	na	24 bu a^{-1}	67.3 bu a^{-1}
ASCS proven yield	na	20 bu a^{-1}	34 bu a^{-1}	24 bu a^{-1}
Total W use, in. a^{-1}	9.2	6.9	6.8	14.7
W Use Efficiency, lb DM $inch^{-1}$	130	0	530.7	727.3
1991 Crop	grass/forb	wheat	fallow	oats
Total DM, lb a^{-1}	1361a	11100b	0	3525a
Percent removed (harvest)	na	22	na	25
Farmer field est. yield	na	23.0bu a^{-1}	na	10.7 bu a^{-1}
Total W use, in. a^{-1}	8.5	12.0	13.9	8.8
W Use Efficiency, lb DM $inch^{-1}$	160	925	0	400.6

Numbers followed by different letters within a region's row by year are significantly different ($p<0.05$)

Summary of Methods Used

Site Selection

Scientists from several disciplines and farmers met on three occasions to determine the issues to be investigated and data to be collected. Based upon the results of these meetings, research issues were determined by representatives from the Experiment Station and Extension Service, the Soil Conservation Service and two farm organizations: the Manitoba-North Dakota Zero-Till Association and the Northern Plains Sustainable Agriculture Society. Common ground and acceptable phrasing were sought, and it was eventually agreed that soil was a non-renewable resource and its current condition would be a primary focus of the study. Farms were to have been successfully managed with specific management practice for ten or more years and matched by labor, size, and general soil type.

The native prairie ecosystem was used as the standard of comparison for farm management practices. Quantification of natural rates of soil erosion, energy consumption/production ratios, total productivity, and nutrient cycling on the native prairie sites were the measurement standards used for comparison with the farm study sites. They were found on private land in the east, and on public lands in the central and west.

The nine farms and three native prairie sites were selected within three eco-regions of North Dakota to assess the biophysical sustainability of each farm using an ecological framework. One farm representative of conventional management practices (i.e. conventional practices of tillage, rotation and input purchases); alternative tillage practices (e.g. no till) and alternative rotations that included a legume in the mix (e.g. beans/oats/alfalfa) were chosen in each region. The native prairie sites were matched with the farms by soil type and represented the controls in this study.

Samples were collected bi-weekly from April through October during 1990 and 1991. The sampling regime consisted of visual observations and soil, plant, and insect samples. Interaction with the nine farmers and their families was considered an integral part of this study. In addition to providing access to their croplands, they submitted historical cropping and fertilizer records. As part of the data collection for the two-year study, the farm families provided field preparation, fertility, planting, emergence, weed control, rainfall, and harvest records. Their farm account records and IRS Schedule F were completely open to the research staff for the duration of the study. The farm cooperators also interacted with the research staff in person on a bi-weekly basis through the growing season.

The sampling regime for this study consisted of an in-depth evaluation of a level, two and one-half acres of a larger field of 80 to 100 acres. Soils on the micro-site were matched to series for all the sites within the eco-region. Classification was done by a soil scientist from the Soil Conservation Service of the USDA.

Soil Physical Characteristics

Ten cumulative soil samples taken each spring and autumn were separated in five depth increments (0-3, 3-6, 6-12, 12-24, 24-48 inches), air dried, and analyzed. Soil moisture was measured gravimetrically. All chemical properties were determined with procedures recommended and used by North Dakota State University and the North Central region (North Central Regional Publication #221, 1988).

Recent interest in the properties of soil organic matter have encouraged further analysis of the components which make up soil organic matter. The "lightfraction" component, composed of very fine particles of organic matter, is considered to be that portion of total organic matter which undergoes the most rapid change (i.e. mineralization). Lightfraction materials were separated from a 20 g. (dry weight) portion of the spring soil sample by suspension in a 1.59 g cm^{-3} solution of sodium iodide with subsequent centrifugation at 5600 x g for 30 minutes (Spycher 1983).

Soil aggregate size was quantified by taking a surface soil sample in mid-summer and separating it into different soil particle sizes, from coarse to fine, through a series of sieves sized 2, 1, 0.5, 0.25, and 0.10 mm (Klute 1986). Numbers are expressed as a percent of the starting soil mass.

Dry soil aggregates of the 1 to 2 mm size were tested for cohesiveness (stability) by repeated submergings in distilled water for three minutes (Kemper and Koch 1966). The remaining aggregate was repeatedly submerged in a 2% solution of sodium hexametaphosphate for 5 minutes; the aggregates were crushed and washed again. Both samples were then dried, net soil weight determined, and percent stable fraction calculated. Bulk density was measured in the spring with a Uhlen sampler at two depths; 0-3 and 3-6 inches.

Biological Samples

Vegetation was measured at the prairie sites from June to September. The biomass samples were collected from square meter areas and separated into grass, forb, standing dead and litter fractions. The samples were weighed, net primary production (NPP) determined (Bonham, 1989) and Kjeldahl nitrogen quantified for each fraction. At the farm sites, replicated quarter meter square samples were taken when the crops were physiologically mature. The biomass was separated as to crop weeds and liter, dried, and weighed to determine NPP a^{-1}. The grain was threshed and weighed to estimate grain yield. Each fraction was ground and quantified for Kjeldahl nitrogen.

Mineralization of nitrogen is the transformation of the organic forms of nitrogen into an inorganic state. This transformation process occurs in the organic matter fraction of the plow layer and is driven by a below ground food web consisting of microbes (bacteria and fungi), microarthropods (mites and springtails), and other soil fauna (nematodes and earthworms). In an attempt to quantify these dynamics, soil cores were taken to a depth of 15 cm (1200 cm^3) on 8 separate dates from June through September. Soil fauna were extracted by salt water flotation (Walter et. al. 1987) and subsequently counted. Bacteria populations were determined by bioassay (Klener 1985). Populations are expressed in log + 1.

Microarthropods (insects, spiders, centipedes, and millipedes) were sampled bi-weekly from June to September. Pitfall traps were constructed by filling 355 ml plastic cups with 178 ml of 70% ethyl alcohol and 1 ml of 50% glycerin. The traps were covered with a crude funnel and placed into the soil so the rim was even with the soil surface. The traps were retrieved after 4 days, samples cleaned, and stored in 70% alcohol. Samples of airborne insects were collected during the same periods by taking 100 sweeps with a beater insect net. Insects caught in the net were removed and placed into paper bags to be frozen for later identification. This sampling was replicated five times for each sample date. All of the insects were identified to family. The families were sorted into predator and herbivore categories after Hagen et al. 1976. (Tables 1 and 2).

A two-way ANOVA was applied to determine significance differences among farm types and farm type versus location. A two-way repeated observation ANOVA was also used when measurements of time and depth were involved. The Tukey test was used to separate means when over-all analysis was significant (Snedecor and Cochran 1967) Principal component analysis (PCA) was used to determine the most significant arthropod trends among treatments; then a cluster analysis was applied to 10 arthropod groups identified by PCA (Ludwig and Reynolds 1988). Multi-response permutation procedures (MRPP), a distribution free permutation test of significance for uneven data (Biondini et al. 1988), was used to determine the significance of the clusters. The results of these tests are reported in the summary portion of this report.

Table 1. Predator families observed in the pitfall traps collected during this study.

Predator families

Spiders	*Agelenidae*	**Beetles**	*Anthicidae*	**Flies**	*Anthomyiidae*	**Bees**	*Andrenidae*
	Amaurobiidae		*Anthribidae*		*Asilidae*		*Anthophoridae*
	Araneidae		*Carabidae*		*Bombyliidae*		*Bethylidae*
	Clubiona		*Cicindelidae*		*Calliphoridae*		*Braconidae*
	Ctenium		*Cleridae*		*Cecidomyiidae*		*Chalcididae*
	Dictynidae		*Coccinellidae*		*Chloropidae*		*Eucoilidae*
	Gnaphosidae		*Corylophidae*		*Culicidae*		*Formicidae*
	Linyphiidae		*Dermestidae*		*Dolichopodidae*		*Halicitdae*
	Lycosidae		*Derpdpmtoda*		*Drosophilidae*		*Ichneumonidae*
	Oxyopidae		*Elateridae*		*Empididae*		*Mutillidae*
	Phalangida		*Endomychidae*		*Mycetophilidae*		*Pompilidae*
	Philodromidae		*Endomychidae*		*Otitidae*		*Pteromalidae*
	Pisauridae		*Histeridae*		*Rhagionidae*		*Sphecidae*
	Salticidae		*Lathridiidae*		*Scatopidae*		*Tenthredinidae*
	Thomisidae		*Meloidae*		*Sciomyzidae*		*Tiphiidae*
	Zoridae		*Melyridae*		*Sepsidae*	**Thrips**	*Phlaiothripidae*
Moths	*Noctuidae*		*Mordellidae*		*Sphaeroceridae*		*Thysanoptera*
	Phralidae		*Mycetophagidae*		*Syphidae*	**Mantid**	*Mantodae*
Lacewing	*Chysopidae*		*Nitidulidae*		*Tabanidae*	**Other**	*Chilopoda*
Dragonfly	*Calopterygidae*		*Pedilidae*		*Tachinidae*		*Dipllopoda*
	Coenagrionidae		*Pselaphidae*		*Thereridae*		*Thysanura*
	Ephemeroptera		*Pyrochoridae*	**Bugs**	*Berytidae*		
	Gomphidae		*Scarabaeoidae*		*Cimicidae*		
Grasshopper	*Acrididae*		*Silphidae*		*Lygaeidae*		
Cricket	*Gryllidae*		*Staphylinidae*		*Miridae*		
Stonefly	*Plecoptera*		*Tenebrionidae*		*Nabidae*		
					Pentatomidae		
					Reduviidae		

Table 2. Herbivore families observed in the pitfall traps collected during this study.

Herbivore families

Beetles	*Brunchidae*	**Flies**	*Agromyzidag*	**Bugs**	*Coreidae*	**Bees**	*Apidae*
	Byrrhidae		*Argidae*		*Rhopalida*		*Apoidea*
	Cerambycidae		*Chiromyzidae*	**Sucking**	*Aphididae*		*Cephidae*
	Chrysomelidae		*Gasterophilidae*		*Cicadellidae*		*Colletidae*
	Curculionidae		*Heleomyzidae*		*Coccidae*		*Megachilidae*
	Lagriidae		*Lauxaniidae*		*Dictyopharidae*		*Siricidae*
	Melandryidae		*Milichiidae*		*Eriococcidae*		
	Noteridae		*Muscidae*		*Flatidae*		
	Oedemeridae		*Mycephilidae*		*Membracidae*		
	Ptiliidae		*Noteridae*				
Moth	*Gelechiidae*		*Oestridae*				
	Hepialidae		*Piophilidae*				
	Hesperidae		*Pipunculidae*				
	Nymphalidaae		*Schizophora*				
	Pieridae		*Sciaridae*				
Grasshopper	*Tettigonidae*		*Simuliidae*				
			Stratiomyidae				
			Tephiridae				
			Trixoscelididae				

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Detailed Site Descriptions

EAST PRAIRIE SITE

Tallgrass prairie ecosystem

Geologic and Social History

Located in the southeastern portion of Ransom county, the east prairie site was geologically part of the Lake Aggassiz formation. The soils derived from silt deposits became waterlogged during times of snow melt and spring and autumn rains. When the European settlers came during the 1870's, the site was producing a luxuriant tallgrass prairie vegetation. First evaluated in terms of wheat production, it became clear that the soil would require drainage.

The individual who homesteaded this site and his neighbors began constructing a drain which channeled runoff from several sections into the Sheyenne River. The east prairie study site was preserved as a result of the presence of the drain, a hill, and a gravel pit which made farming this particular tallgrass prairie remnant inconvenient. This land was eventually transferred from the original homesteader to the family of the present owner. Leaving this prairie remnant uncultivated became more than a matter of convenience for the descendants of this pioneer family who recognized the historic and esthetic value of the site.

The east prairie site was used as a standard for comparison with the three other farms used in this study of the Red River Valley region of eastern North Dakota. The sampling regime consisted of an in-depth evaluation of a level, one-acre portion of the 80-acre site. The Beardon soil type was used as the reference soil for all the sites in the tallgrass prairie region and it was verified by a soil scientist from the Soil Conservation Service of the USDA. Drainage on the east prairie site was poor, runoff was slow, and permeability was slow to moderate because of the fine texture of the Beardon soils. All of the characteristics described for the A, B, and C soil horizons (Table 1.11) were associated with wetness.

Soil Physical and Nutrient Characteristics

Measurements of the soil physical characteristics such as bulk density, wet aggregate strength and dry aggregate size were taken from the east prairie site in 1990 and 1991 (Table 1.11). Since the only disturbance to this site was from grazers moving through, the soil physical measurements remained similar for both years of the study. Fine particles (0-25 mm) comprised 3 percent of the soil aggregate sample (Figure 1.11).

Table 1.11. Summary table of soil physical and chemical characteristics for the east prairie site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	4.42	2.57	3.55	1.76	2.53
fall	1.86	0.83	2.08	2.17	1.39
'91 spring	2.46	1.65	4.93	1.99	1.98
fall	0.36	0.34	0.35	0.48	0.20
Ammonium mg kg^{-1}					
'90 spring	11.1	4.95	3.99	2.41	2.03
fall	5.63	3.58	2.50	2.48	2.84
'91 spring	7.16	5.03	3.88	2.52	2.19
fall	12.25	11.53	8.02	5.00	4.11
Phosphorus mg kg^{-1}					
'90 spring	15.5	9.0			
fall	11.0	6.0			
'91 spring	12.0	6.5			
fall	9.5	5.0			

Soil Physical Characteristics

Horizon Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A 0-8	clay	granular	strong	many	
B_k 9-15	clay	weak SBK	strong	many	
AB_k 26-21	clay	weak SBK	strong	many	dk.color from A horizon
C_1 22-36	clay	massive	strong	few	common md. gry. fine yl. mtles.
C_2 37-43	clay	massive	neutral	none	common fine yl. mtles.gry.matrix
C_3 44-48	clay loam	massive	strong	none	many md.dk.yl.mtles.acc.Fe

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
0.62g cm^3	8.0	9.00%	16,865	1.12%	189
0.62cg cm^3	7.6	8.30%	8,380	0.34%	29

Aggregate Stability
89%
96%

Abbreviations defined:

*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.

**Bulk densities presume a particle density of 2.65 g cm^3;n soils with high rates of organic matter this assumption may be in error.

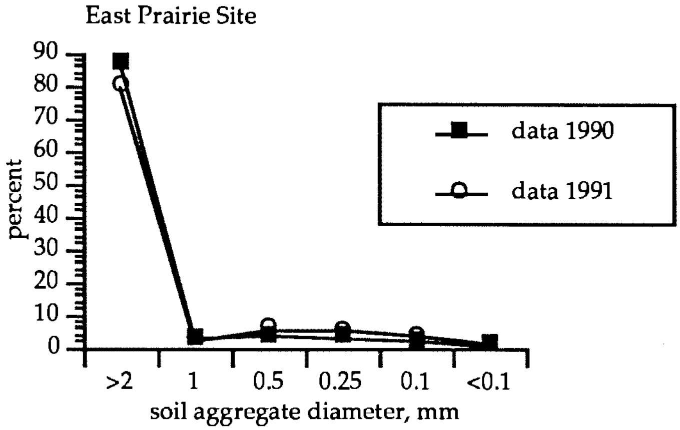


Figure 1.11. Soil aggregate size distribution for 1990 and 1991 east prairie site.

In a tallgrass prairie ecosystem, nitrogen (N) enters the soil through atmospheric precipitation, release of organically bound nitrogen attached to particulate matter, and nitrogen fixation by bacteria and blue green algae. Nitrogen exits the system through volatilization of ammonia, bacterial denitrification, and nitrification followed by subsequent leaching. In an attempt to trace the fate of nitrogen in the system, soil tests were conducted in the spring and autumn of 1990 and 1991 (Table 1.11). In addition, nitrogen was monitored in a portion of the soil organic matter and plant parts (i.e., leaves, stems, and seeds) throughout the growing season (Figure 1.12).

In most natural systems, nitrogen tends to reside more in living or decomposing plant tissue than in soil solution itself (Stevenson 1982). Data from the east prairie site show that both free nitrate and ammonium exists in low concentrations and the ammonium levels exceed the nitrate levels on both spring and autumn sampling dates in both years of the study. Nitrogen levels were higher in the plow layer and they were generally higher for the 1991 production year (Table 1.11). The nitrate-ammonium relationship in the native prairie ecosystem is tightly bound within a nitrogen mineralization and immobilization transformation cycle.

Organic matter from the prairie plant residues were the substrate for the mineralization process in the below ground food web. From the spring sample, the lightfraction component of soil organic matter was extracted. The sharp difference in the values (Table 1.11) for the two years of tests was attributed to the drought which preceded the spring 1990 tests.

Nitrogen uptake by plants was measured during 1990 and 1991 by clippings taken at four times during the season (1991 data presented in Figure 1.12). The nitrogen content of the above ground plant material depended upon age and component (i.e., forbs, litter, etc.). Within a single season, living plants generally decreased in N concentration while litter increased.

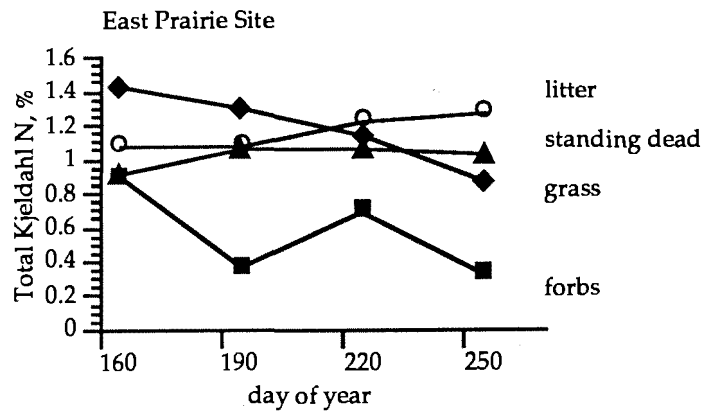


Figure 1.12. Total Kjeldahl nitrogen, %present in above ground biomass at the east prairie site during 1991. Definitions are live grass and forbs, plant materials that haven't fallen to the ground (standing dead), and recognizable plant materials on the ground (litter).

Activity of the soil fauna on the east prairie site was quantified by extraction made from soil cores taken on eight separate sample dates from June to September (Figure 1.13). The population of microbes (bacteria) in 1990 were the lowest in mid-July (day of year 205) whereas the springtail and mite populations were at their peak during this time. Spring-tail populations tended to increase in the fall but over the season their numbers are the lowest of the fauna quantified.

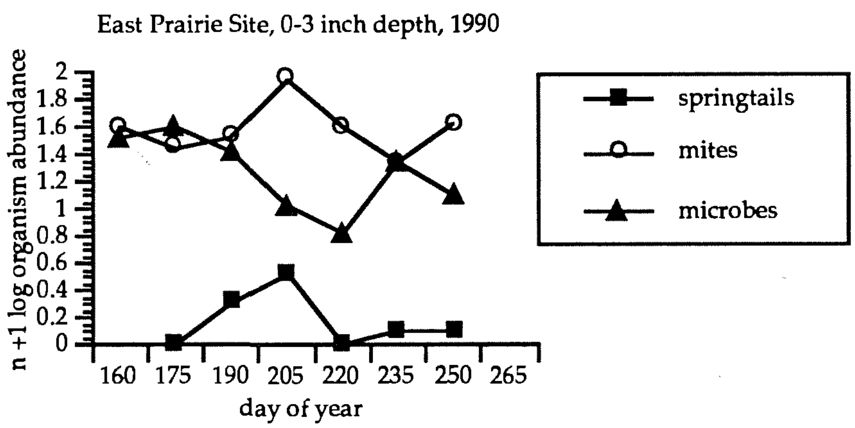


Figure 1.13. Soil fauna population measurements at one soil depth and eight sample dates for 1990. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

There were nine sample dates, one earlier and one later than in the 1990 sampling period (Figure 1.14). Microbe popultaions were level throughout the 1991 season. Springtail populations rose and fell throughout the season with three high points, day of year 160 (June 9), 190 (July 7) and 250 (September 7). The peak mite population was day of year 220 (August 8).

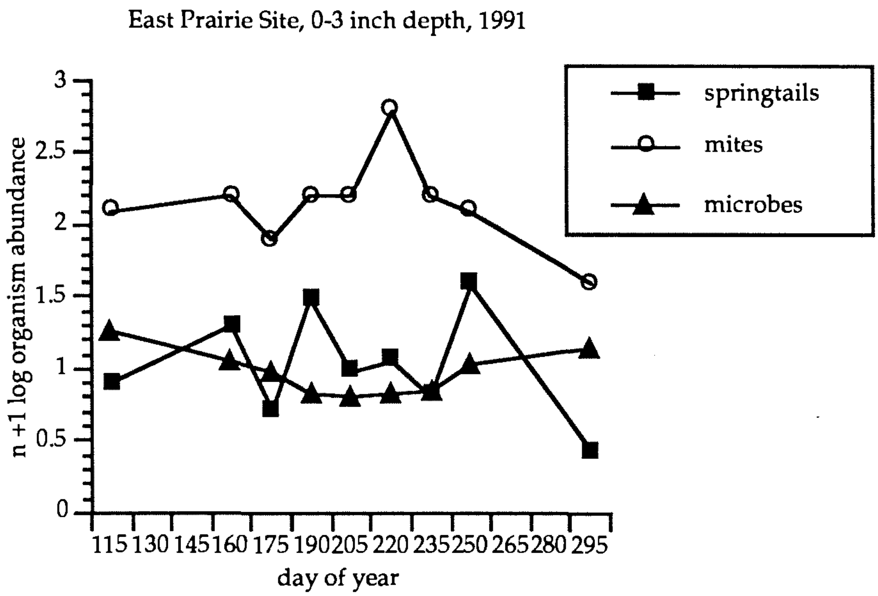


Figure 1.14 . Soil fauna population measurements at one soil depth and nine sample dates for 1991. Abundance springtails and mites -= 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

In addition to microarthropods, other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented. Pitfall traps were collected on seven successive sample dates for 1990 and six sample dates in 1991 (Figure 1.15). The predominant arthropods collected were as follows: spiders (8 families), beetles (11 families), flies (11 families), and bees (7 families). There was a higher number of families represented in 1991, the year of higher precipitation.

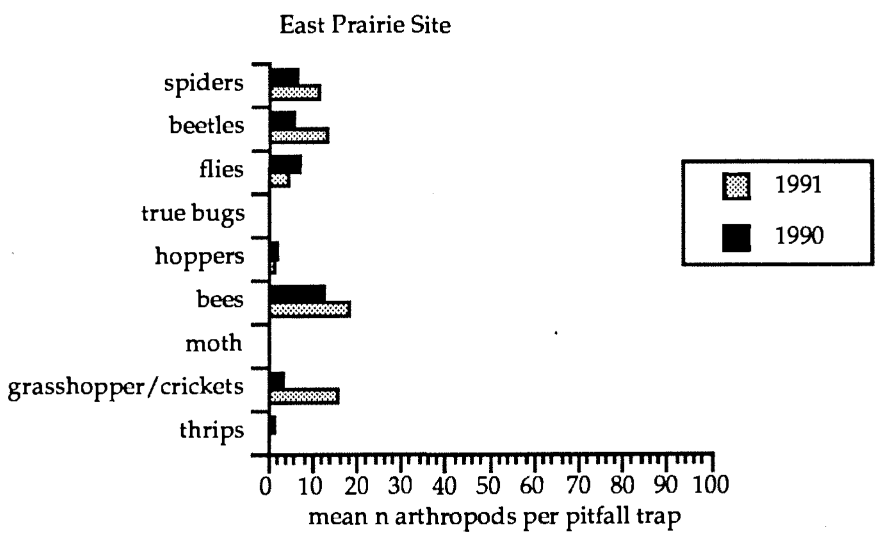


Figure 1.15. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 6 sample dates in 1991. sample size = 12 oz cup set at soil level for 4 consecutive days.

The predominant families of arthropods trapped in 1990 were as follows: wolf spider *(Lycosidae)*, crab spider *(Thomisidae)*, ground spider *(Carabida)*, blister beetle *(Meloidae)*, long legged fly *(Dolichopodidae)*, buffalo gnat *(Simuliidae)*, ant *(Formicidae)*, Ichneumon

wasp *(Ichneumonidae)*, and crickets *(Gryllidae)*. The predominant families in 1991 were as follows: wolf spider, ground beetle, carrion beetle *(Silphidae)*, buffalo gnat, flower fly *(Syrphidae)*, ants, and crickets.

The Margalef index is an index of diversity. In this study it was used to measure the diversity of insect families. The diversity of predators and herbivores remains relatively constant across time within a year and across years (Table 1.12)

Table 1.12. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores.

Margalef Index of Pitfall Trap Insects

East prairie	**Predators**						**Herbivores**					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	1.54	3.78	4.94	4.15	4.46	2.97	0	1.04	0.76	1.33	1.17	0.64
1991	4.75	3.59	4.05	4.76	3.44	4.02	0.62	1.06	1.26	0.88	0.74	0
mean	3.15	3.69	4.50	4.46	3.95	3.50	0.31	1.05	1.01	1.11	.96	.32

Plants Present

The vegetation present (complete list Table 1.13) on the tallgrass prairie site consisted primarily of grasses and forbs. The grasses were both cool-season and warm-season species of the bunchgrass and sod-forming types. The predominant cool-season grass was Kentucky bluegrass (*Poa pratensis*), a sod-forming, introduced species. The predominant warm-season grasses were big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*) both of which are sod-forming, native species. Two nitrogen-producing forbs present on the site were Indian milk vetch (*Astraglus aboriginium)* and yellow clover (*Melilotus officinale*). Yellow clover was the predominant forb. A total of twelve grass species, two sedge species, and twenty forb species were present on this site. Two shrubs present on the site, prairie rose (*Rosa woodsii)* and buckbrush (*Symphoricarpos albus*) occurred at a frequency of 1 percent and 8 percent, respectively.

Table 1.13. Plants present in the east prairie site.

Tallgrass Prairie Species		
Agropyron trachycaulum	*Sorghastrum nutens*	*Convlvulus arvensis*
Agropyron smithii	*Carex filifolia*	*Euphorbia spp*
Agrostis stolonifera	*Carex heliophila*	*Fritillaria pudica*
Andropogon gerardi	*Carex lanuginosa*	*Lactuca serriola*
Astraglua aboriginum	*Allium Textile*	*Lactuca oblongifolia*
Boutelous curtipendula	*Ambrosia psilstachya*	*Liatris ligulistylis*
Bromus inermis	*Antennaria parvifolia*	*Linum ridium*
Juncus balticus	*Artemisia ludoviciana*	*Ratibida columnifera*
Panicum rirgatum	*Asclepias syriaca*	*Sanicula marilandica*
Poa pratensis	*Astraglus aboriginum*	*Solidago nemoralis*
Spartina pectinata	*Cirsium flodmanii*	*Sonchus arvenis*
		Trifolium campestre

Soil Moisture

Soil moisture (Table 1.14) was determined on this site gravimetrically to a depth of 48 inches during spring and autumn. Precipitation estimates recorded at the nearest weather station during this period totaled 15.2 inches of rainfall for 1990; 18.1 inches for 1991. Evapotranspiration measurement was estimated to be 16.2 inches for 1990; 20.5 inches for 1991.

Table 1.14. Soil moisture at 0-48 inch sampling depth for spring and fall 1990 and 1991.

East Prairie Site Soil Moisture

	0-3	3-6	6-12	12-24	24-48	Total	Precip	est W
'90 spring	1.05	0.71	2.50	3.59	4.91	12.95	15.20	16.2
fall	0.77	0.75	1.89	3.39	5.19	12.00		
'91 spring	1.07	1.20	3.57	4.66	7.92	18.42	18.10	20.5
fall	0.81	0.94	1.95	3.19	3.39	16.01		

Management

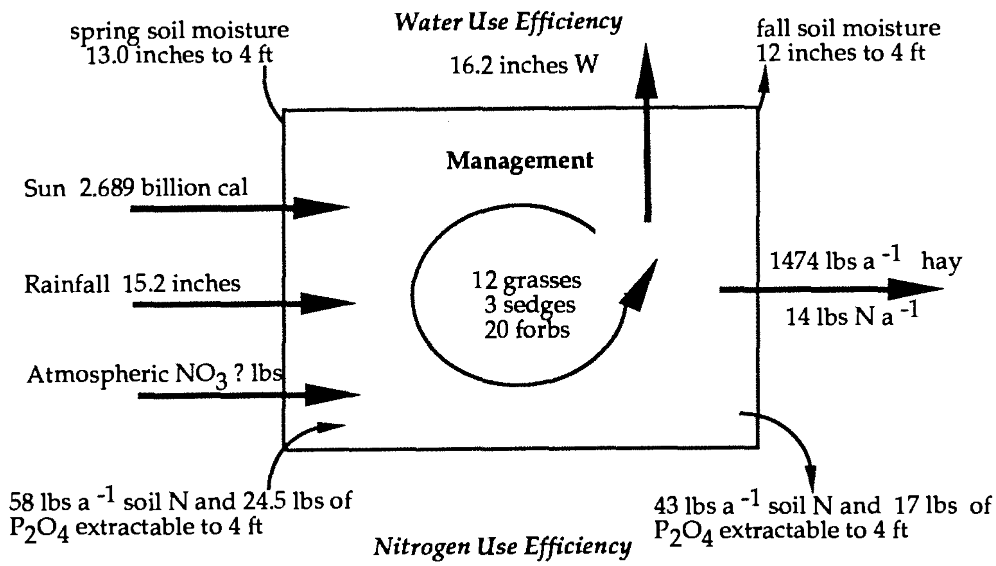
Management practices on this site have consisted of haying for the past 75 years. Approximately 1,500 pounds (dw) of hay per acre has been removed each year; this was equivalent to 14 pounds of nitrogen per acre. The plant species comprising the hay crop consisted mostly of the twelve grass species, with lesser amounts of two sedge species, and twenty forb species. Because of the extended time period of this management practice, it was assumed that the site has reached an equilibrium in response to such annual harvests.

In 1990, cattle grazing, at the rate of one animal unit per acre for one month, was introduced as a new management practice to this system. The impacts of this new management practice have not been quantified, but based upon published research results on the impacts of grazing and initial observations of this site, certain biotic effects may be expected.

Production and Resource Use Efficiency

Harvestable production from the site took place in a single cutting of hay in late summer. The 1990 harvest was estimated at 1,471 pounds of dry matter per acre and 2,015 pounds in 1991. Using pre- and post-season soil samples taken to a 48-inch depth, total gravimetric water, nitrate, and ammonium content were determined. Coupled with locally recorded precipitation amounts and an undetermined amount of atmospheric and legume nitrogen input, gross nitrogen and water use efficiencies were calculated (Figure 1.16 and 1.17).

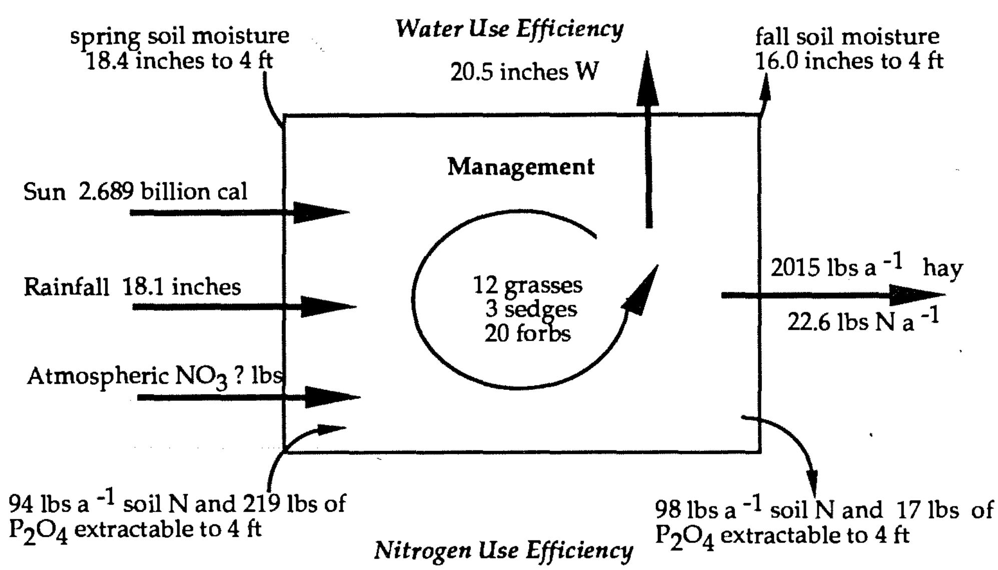
$$\frac{1966 \text{ lbs a}^{-1} \text{ dry matter harvested}}{16.2 \text{ inches W}} = 121 \text{ lbs inch W}^{-1}$$



$$\frac{1966 \text{ lbs a}^{-1} \text{ dry matter harvested}}{15 \text{ lbs N a}^{-1}} = 131 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 1.16. Gross inputs, outputs, and efficiencies from the east prairie site during the summer of 1990.

$$\frac{3010 \text{ lbs a}^{-1} \text{ dry matter harvested}}{20.5 \text{ inches W}} = 147 \text{ lbs inch W}^{-1}$$



$$\frac{3010 \text{ lbs a}^{-1} \text{ dry matter harvested}}{1 \text{ lbs N a}^{-1}} = 3010 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 1.17. Gross inputs, outputs, and efficiencies from the east prairie site during the summer of 1991.

EAST CONVENTIONAL SITE
Tallgrass prairie ecosystem

Geologic and Social History

Located in Steel and Trail Counties, the east conventional site was near the Campbell beachridge of glacial Lake Aggassiz and the meandering north branch of the Goose river. Lands once covered by tallgrass prairie became part of North Dakota's agricultural acreage during the expansion period of the 1870's. It was the time of the "Bonanza Farms" and the sod was turned to plant wheat (Drache 1964).

The present owner's ancestors immigrated from Europe to North Dakota after the peak of the Bonanza farm boom. His grandfather, uncle, father, and he all served as the farm manager for the same family on the same land for over 75 years. When the second generation of owners lost the land in non-agricultural speculation, this farmer rented other acreage in the same vicinity. The land unit of the east conventional farm was 1200 acres, typical size for one sub-division of a Bonanza Farm.

During the Wisconsin glaciation period, the Dakota glacier coming out of Manitoba and Saskatchewan and the Minnesota glacier coming out of Manitoba and Ontario merged just north of this geographical area. A great, glacial river of melt water formed between the two glaciers depositing silt and clay in the Elk Valley Delta which lies to the west of this site. The Delta was located at a higher elevation and was bounded on the east by a ridge formed by a moraine remaining from the Minnesota glacier. The river that formed the delta no longer exists. The topography of the delta was so level that creeks formed and then dissipated into a marsh (Willard, 1921). Drainage in the form of saline seeps occured on the western section of this site causing a reduction in the potential crop productivity on those acres.

The bulk of the cultivated soils were formed from the homogenized granites, limestone, and shale that were sorted into sand, silt, and clay by the wave action of Lake Aggassiz. Sand and gravel were deposited along the shorelines; silt and clay became the flat lands of this area. The tallgrass prairie thrived on these nutrient rich soils for approximately 9000 years prior to European settlement (Bluemle, 1977). Vegetation, seasonal climate, and time created these deep, brown, chernozem soils which were a rich black color when freshly tilled.

The sampling regime for this study consisted of an in-depth evaluation of a level, one-acre portion of a 100-acre field. The closest match to the index soil, Bearden, was Glyndon (Table 1.21) as verified by a soil scientist from the Soil Conservation Service of USDA. It was coarser in texture tending more toward loam than clay (30-35%) and consisted of deep somewhat poorly drained soils.

Soil Physical and Nutrient Characteristics

Measurements of the soil physical characteristics, bulk density, wet aggregate strength, and dry aggregate size were taken from the east conventional site in 1990 and 1991 (Table 1.21). Acreage that produced a barley crop the previous year showed a spring bulk density measurement of 1.21g cm^{-3} while acreage that produced a Navy bean crop the previous year measured a bulk density of 0.95cm^{-3} for the plow layer.

Table 1.21. Summary table of soil physical and chemical characteristics for the east conventional site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	11.77	16.54	13.17	11.79	5.82
fall	10.83	6.46	6.05	3.74	5.02
'91 spring	15.21	13.75	3.92	2.81	2.48
fall	7.24	5.78	2.69	1.93	1.81

Ammonium mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	3.62	3.27	2.34	1.96	2.21
fall	65.05	10.10	3.74	2.45	2.45
'91 spring	8.26	4.02	2.46	2.26	2.20
fall	3.51	4.06	5.10	4.14	5.08

Phosphorus mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	11.5	6.0			
fall	11.0	5.0			
'91 spring	16.0	4.5			
fall	15.5	8.5			

Soil Physical Characteristics

Horizon	Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
Ap	0-11	clay loam.	weak SBK part to gran	slight	common	
AB_k	11-19	clay loam	weak SBK	violent	common	
B_{k1}	19-31	sandyclay loam.	weak SBK	violent	few	few fine br.mtles.
B_{k2}	32-37	clay loam	weak SBK	violent	few	few fine yl. mtles.
C_1	38-48	clay loam	massive	strong	none	many md. yl. mtles.

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
1.12g cm^3	8.0	2.48 %	805	1.40%	11
0.95g cm^3	8.0	3.08 %	1835	0.82%	15

Aggregate Stability
64 %
97%

Abbreviations defined:
SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

Surface soil samples for aggregate size distribution were separated into different soil particle sizes in mid-July of 1990 and 1991. Figure 1.21 shows the effect of the different crops present at the time of sampling: beans in 1990 and barley in 1991. Fine aggregates of less than 0.25mm were 38 percent of the gross sample for the beans and 14 percent for the barley acreage. The water stable aggregates of the east conventional site differed by year and by crop. The aggregates from the 1990 bean acreage were 64 percent water stable; the aggregates from the 1991 barley acreage were 96.5 percent water stable (Table 1.21).

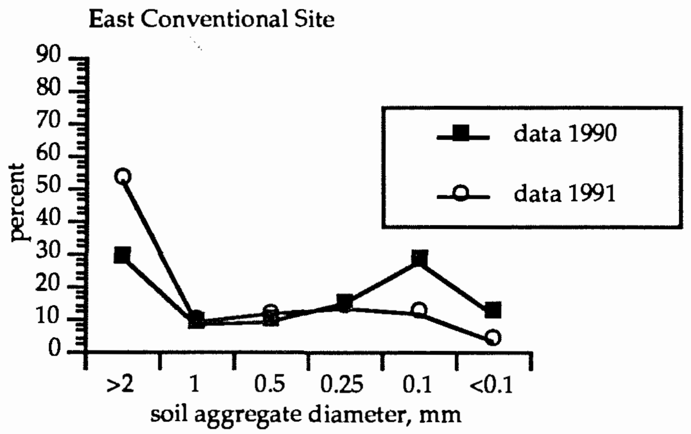


Figure 1.21 Soil aggregate size distribution for 1990 bean acreage and 1991 barley acreage on the east conventional site.

In a conventional farm agroecosystem, nitrogen (N) enters the soil through atmospheric precipitation, decomposition of organic matter, application of industrial fertilizer, and nitrogen fixation. N leaves the system through crop harvest, volitization of ammonia, bacterial denitrification, and nitrification followed by subsequent leaching. The farmer of the east conventional site subscribed to a soil testing service which conducted tests during the autumn for the past several years. Based on the service's measurement, recommendations for the crop of interest, and the farmer's experience, 40 lbs a^{-1} of 11-52-0 (4.4 lbs actual N) and 10 lbs a^{-1} of 36 percent 2NC Sulfur were applied prior to seeding a 1990 crop of Navy beans.

Soil tests conducted in the spring of 1990 prior to seeding showed 122 lbs a^{-1} of free nitrate and ammonium at the 48-inch soil depth.(Table 1.21). The upper levels of the autumn soil nitrogen measurements reflect the 50 lbs a^{-1} of anhydrous ammonia applied in anticipation of the 1991 barley crop. Other soil factors monitered on this site were pH, organic matter, and the lightfraction component of organic matter (Table 1.21).

The N mineralization and immobilization transformation cycle was affected by factors such as the residual N remaining from the previous year, the amount, source, timing, and method of application of the current year's infusion of nitrogen, the current year's crop response to climatic factors such as precipitation and temperature, and the way in which all of these factors affected the soil biological system. The microbial activity of the belowground food web on this site was affected by the chemical and physical soil factors. Bean and barley crops rotated on the east conventional site supplied the organic matter, but they also competed for the minerals that were released through the mineralization process.

In an attempt to quantify the effect of these dynamics on soil fauna (bacteria, mites, and springtails), soil cores were extracted to a depth of 15 cm on eight separate days from June to September (Figure 1.22). Activity of the microbes, springtails, and mites on the east conventional site tended to range the full depth of the plow layer but only the upper three inches are reported in this study for comparison purposes.

The 1990 population of these organisms demonstrated great variation in densities throughout the season. Microbe populations start out highest in the spring and decline in abundance in autumn. Springtail populations were highest for day of year 210 (July 29) when the mite population was at a low level. Springtail prey on bacteria and fungi, transport bacteria and fungi to other field locations, and feed on dead plant material.

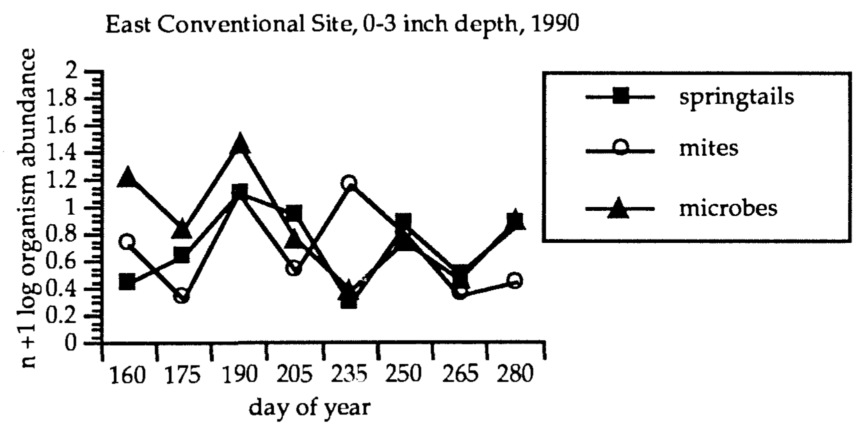


Figure 1.22. Soil fauna population measurements at one soil depth and eight sample dates for 1990. The crop grown on this site was beans. The beans were harrowed on day of year 165 (June 14) and harvested on day of year 267 (September 24). Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

For the 1991 barley crop the springtail and mite populations tend to peak simultaneously on day of year 160 (June 9), 205 (July 24), and 235 (August 23). The microbe population was rather flat for the season (Figure 1.23).

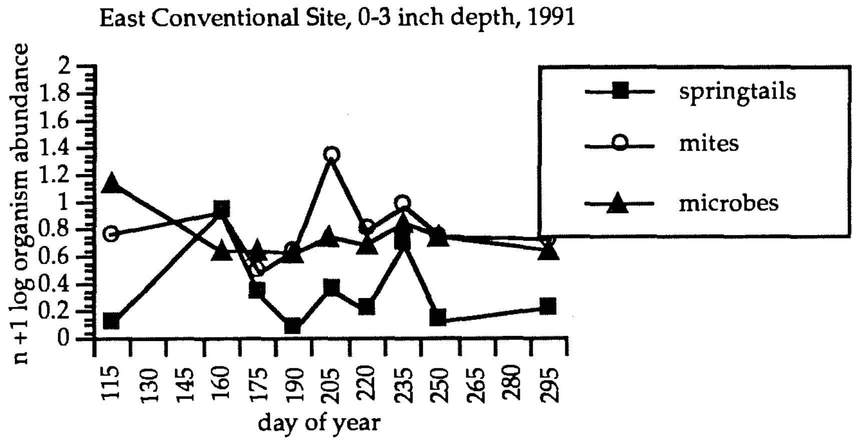


Figure 1.23. Soil fauna population measurements at one soil depth and nine sample dates for 1991. The crop was barley; it was harvested day of year 173 (July 22), field cultivated day of year 246 (September 3) and disked before the last sample date day of year 295 (October 22). Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

The immobilization phase of the N cycle on this site was evident in the potential gaseous N fixation by rhizobia in relationship with the navy beans. The amount of N fixation depends on the N level present, soil physical condition, presence of nitrifiers, and low populations of bacteriophages. Soil test recommendations allow N credits of 25 lbs a^{-1} if the previous crop was navy beans (NDSU, 1991). In the presence of high levels of nitrogen, nodule formation in leguminous crops is reported to be depressed. Nodule formation was not quantified on the east conventional site.

In addition to microarthropods, other arthropods were quantified to obtain a better understanding of the biodiversity on this site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented. Pitfall traps were collected on seven successive sample dates for 1990 and six sample dates in 1991 (Figure 1.24). The predominant arthropods collected in 1990 were as follows: spiders (5 families), beetles (7 families), flies (7 families), and bees, true bugs, and hoppers (each 2 families). There was more diversity observed in the 1991 collections.

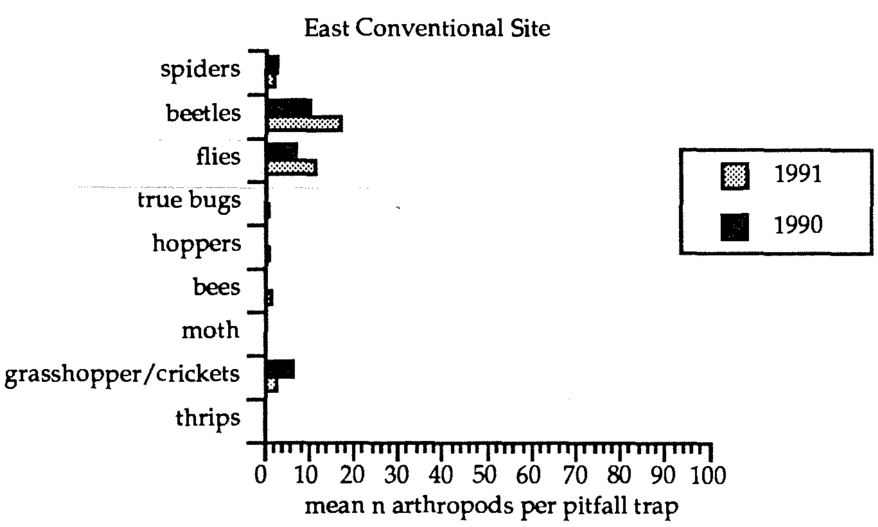


Figure 1.24. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 6 sample dates in 1991. Sample size = 12 oz cup set at soil level for 4 consecucitive days.

Daddy longlegs spiders *(Phalangida)*, ground beetles *(Carabidae)*, carrion beetles *(Silphidae)*, buffalo gnats *(Simuliidae)* and small metalic burrowing bees *(Halicitdae)* were the predominant families in the traps in 1990. In 1991 there were no burrowing bees but there were leafcutting bees *(Megachilidae)*; there was also long-legged flies *(Dolichopodidae)* in these traps.

The Margalef index of insect family diversity shows no diversity among herbivores for 1990 and except for day of year 190 low diversity among predators. The crop, Navy beans, was managed to control crop pests. There was more diversity among families of herbivores collected from the 1991 barley crop but there was also more diversity among predators. Once the barley crop was seeded it was relatively undisturbed.

Table 1.22. The Margalof index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores.

Margalef Index of Pitfall Trap Insects

East conventional	**Predators**						**Herbivores**					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	1.55	1.94	3.23	1.57	2.04	0	0	0	0	0	0	0.76
1991	5.52	1.84	3.56	4.74	3.60	1.08	1.12	0.18	0.96	1.80	0.88	0
mean	3.54	1.89	3.40	3.16	2.82	.54	0.56	0.09	0.48	0.90	0.44	0.38

Plant Species Present

The vegetation present (Table 1.22) consisted primarily of forbs in 1990 and grasses in 1991. The typical crop rotation for this site was beans *(Phaseolus Vulgaris* 'Crestwood'*)* and barley *(Hordeum vulgare* 'Pioneer B1602'*)*. In 1990 no weeds were observed until mid July when smartweed *(Polygonum coccineum)* appeared in the lower areas. In late July there was some evidence of mustard *(Sinapis arvensis)* and green foxtail *(Setaria virdis)*. Mustard was detected in one of five samples during mid June of 1991. No other invading species were present until late July when a small amount of green foxtail and wild buckwheat *(Fagopyrum tataricum)* was detected.

Table 1.22. Plants present in the conventional agroecosystem.

Conventional System Species

Phaseolus vulgaris	*Polygononum coccineu*	*Sinapis arvensis*	*Setaria virdis*
Hordeum vulgare	*Fagopyrum tataricum*		

Nitrogen uptake by plants was measured during 1990 and 1991 from clippings taken at crop physiological maturity. The navy bean crop straw had total Kjedahl nitrogen present of 1.53 percent whereas the beans had 4.09 percent. The 1991 barley straw measured 1.37 percent total Kjedahl nitrogen, the grain 2.24 percent, and one of the clippings had weeds which tested 3.03 percent.

Soil Moisture

The amount of plant available soil moisture (Table 1.23) is an important factor in determining plant growth. Soil moisture was determined at this site by gravimetric sampling during spring and autumn of 1990 and 1991 to a depth of 48 inches. Precipitation estimates recorded at the nearest weather station during this period totaled 13.52 inches of rainfall for 1990 and 17.5 inches for 1991. Water use was estimated to be 11.3 inches for the 1990 bean crop; 22.7 inches for the 1991 barley crop.

Table 1.22. Soil moisture at 0-48 inch sampling depth for spring and fall 1990 and 1991.

East Conventional Site Soil Moisture

	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.63	0.65	1.46	2.01	6.80	11.55	13.50	11.30
fall	0.46	0.62	1.80	3.25	7.69	13.82		
'91 spring	0.57	0.70	1.57	3.34	8.70	14.88	17.50	22.70
fall	0.43	0.53	1.16	2.38	5.10	9.60		

Management

Management practices on this site have consisted of a bean/barley rotation. The field operations of the 1989 autumn following the barley crop were disking followed by chisel plowing at which time granular trifluralin was applied. Just prior to seeding the 1990 crop, the site was cultivated with a multiweeder and subsequently dragged with a Danish tine harrow the day before planting in late May. The Crestwood Navy bean seeds treated with captan(Captan 20™ @ 3oz bu^{-1}), and streptomycin was seeded in rows with chlorpyrifos (Lorsban 4E™ @ 3/4 lb a^{-1}) insecticide. Fourteen days after seeding the field was dragged; thirty days after seeding the field was sprayed with a post emergence broadleaf herbicide (bentazon, Basagran™,1pt a^{-1}).

Fall operations following the bean crop included a light disking to spread the straw and then an anhydrous ammonia application.

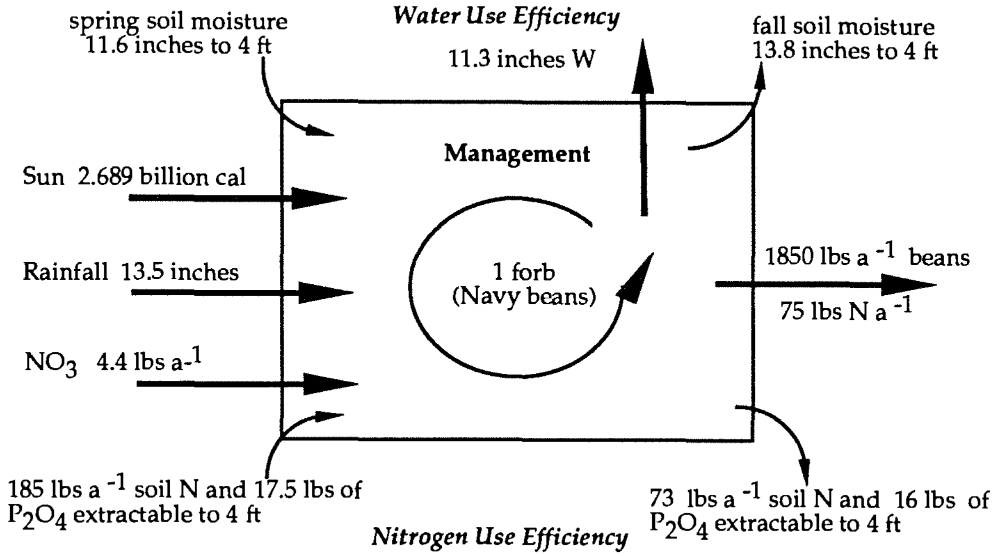
Spring operations for the 1991 barley crop began with multiweeding the day before planting. Pioneer B1602 barley (rate 1.5 bu a^{-1}) was sown in mid March; nutrients, (N and phosphorus), were applied with the drill pass. The field was harrowed two days later and subsequently sprayed with a herbicide (MCP ester) after 30 days.

Production and Resource Use Efficiency

Harvestable production from the site took place by straight combining the navy bean crop in early September. The net primary production (NPP) for 1990 was 5012 lbs a^{-1} of dry matter; of this 1850 lbs were removed as marketable crop (farmer field estimate 1082 lbs a^{-1}) equivalent to 75 pounds of nitrogen a^{-1}. The 1991 barley crop was swathed and combined in late July. NPP was 10,023 lbs a^{-1} of dry matter; of this 2599 lbs a^{-1} of grain (farmer field estimate 54 bu a^{-1}) were removed. N equivalent for the barley was 58 lbs a^{-1}.

Using pre-season and post-season soil samples taken to a 48-inch depth, total gravimetric water, nitrate, and ammonium content were determined mathmematically. Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen and nitrogen inputs, gross nitrogen, and water use efficiencies were calculated (Figure 1.25 and 1.26).

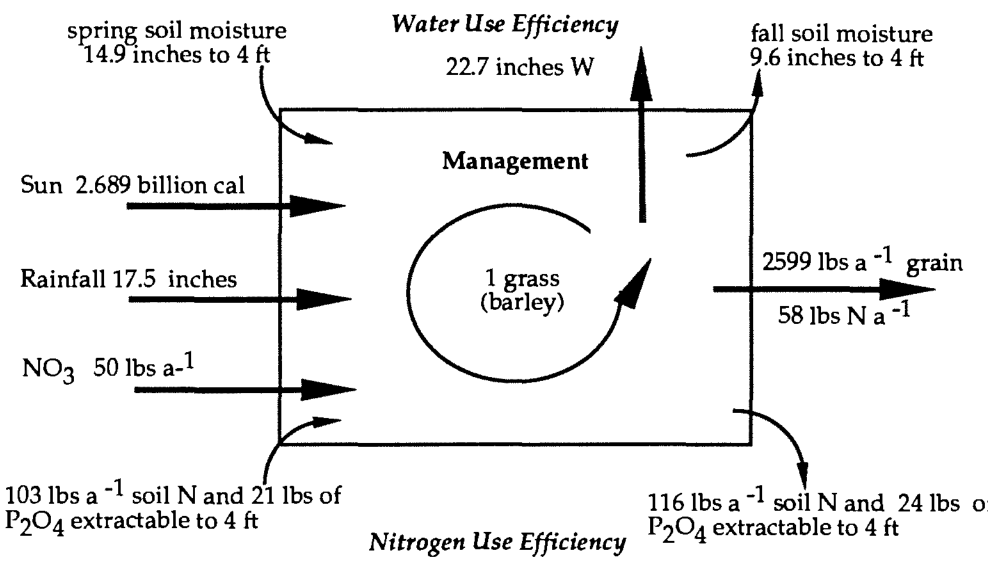
$$\frac{5012 \text{ lbs a}^{-1} \text{ dry matter harvested}}{11.3 \text{ inches W}} = 445 \text{ lbs inch W}^{-1}$$



$$\frac{5012 \text{ lbs a}^{-1} \text{ dry matter harvested}}{112 \text{ lbs N a}^{-1}} = 45 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 1.25. Gross inputs, outputs, and efficiencies from the east conventional site for 1990. inputs were included in the 73 lbs a^{-1} autumn soil N.

$$\frac{10{,}023 \text{ lbs a}^{-1} \text{ dry matter harvested}}{22.7 \text{ inches W}} = 442 \text{ lbs inch W}^{-1}$$



$$\frac{10{,}023 \text{ lbs a}^{-1} \text{ dry matter harvested}}{1 \text{ lbs N a}^{-1}} = 10{,}023 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 1.26. Gross inputs, outputs, and efficiencies from the east conventional site for 1991. The 50 lbs a^{-1} of N inputs were included in the 103 lbs a^{-1} N amount.

EAST NO-TILL SITE
Tallgrass prairie ecosystem

Geologic and Social History

Prior to the formation of Lake Agassiz, glacial ice advanced over steep escarpments of Macintosh granite; the internal stress resulted in shearing (Bluemle 1977). Large amounts of rock and sediment were forced to the top, front, and along the shear planes of the glacier. Insulated by these deposits, the underlying layer of ice took several thousand years to melt. After the glacier melted, it left behind a topography characterized by slumps and slides. This type of topography, typical of a dead ice moraine, was located to the south, east, and west of the no-till site. This natural basin, fed by the Sheyenne River, became Glacial Lake Sargent (Willard, 1921).

During the period of the Wisconsin glaciation, the Sheyenne River was reformed. The river changed its direction of flow from south to east at Lisbon, North Dakota. The source of water for Lake Sargent was eliminated and the Wild Rice River drained the area into glacial Lake Agassiz. Collapsed lake sediment and till which were deposited as a result of this course change (Bluemle 1977) comprise the parent material of the soils on the east no-till site.

Ancient artifacts, such as petroglyphs found near this site were believed to date back to the great north to south migration of the indigenous peoples along the Old Game Trail (Thorifinnson 1976). These petroglyphs were believed to have been the tools used by ancient astronomers in predicting sunrises and locating the North star. By noting the changing location of the setting sun between the hills, these petroglyphs were used to mark times of solstice and equinox. One of these petroglyphs became the altar stone of the Sioux Nation.

There was little pressure to allow European settlers onto territory occupied by Native Americans so long as ample acreage of fertile, accessible, and unclaimed land was available elsewhere (Tyler 1973). Regional politicians, however, would not tolerate having the state divided by the Great Sioux Reservation. These elected officials asserted that it was like a wall dividing the eastern part of the state from the western portion (Olson 1965). In addition, pressure was being exerted by the railroads to establish a route west. As a result Congress passed the Severalty Act of 1887 and President Cleveland signed it one week prior to his leaving office. The intent of this legislation was to make Native Americans individual landowners and farmers. The reservation was divided into six smaller reserves and the "surplus" lands were designated as public domain to be sold at fifty cents per acre (Olson. 1965). Acres comprising the east no-till site were once part of the Sioux Reservation.

The lands comprising Sargent county were a connecting link for much of the historic east-west movement of survey parties, military expeditions and settlers. It was the northern most trek of the Oregon Trail and an obvious route for the railroads to follow. The Northern Pacific, Soo Line, and the Great Northern were the three major railroad lines of the upper-midwest that cross this county. These branchlines are currently active but no longer under the original management regime.

The first Euro-American settler came to this county in 1878 (Thorifinnson, 1976). Railroad crew members remained in the area to farm and settlers came to homestead and purchase Indian allotment lands. The first crop that replaced the native tallgrass prairie was flax. Then wheat and durum were grown for cash crops and oats for cow and horse feed. As early as 1913, the county hosted a corn sweepstakes.

By 1930 the lands were a dust bowl. As described by Thorifinnson (1976), "dust filtered into everything, buried fences and filled farm yards. Fields were eroded to the plow sole, six to eight inches deep, lighter soils were eroded much more. ....blowouts as deep as 20 feet in the sandier soil and dunes were equally high." The county's farmers acted to reverse the erosion. They organized two Soil Conservation Districts and devised a plan to control wind and water erosion by planting alfalfa and grass, started watershed programs, farmstead plantings, and wildlife and recreation developments.

The present farmer of the east no-till site was actively engaged in the leadership of the Wild Rice Soil Conservation District. During the late 1970's he embarked on a farm management plan to control erosion and conserve moisture by using no-till practices. Through his leadership and service of custom seeding, this county has 25,000 acres in small grains, 15,000 acres in soybeans and 5,000 acres in corn under no-till management.

The sampling regime for the east alternative tllage site consisted of an in-depth evaluation of a level, one acre portion of an 84 acre field. The reference soil was Bearden (Table 1.31) as verified by a soil scientist of the Soil Conservation Service of the USDA. Once covered by the native vegetation of the tallgrass species, it was used for the production of small grain, flax, corn, soybeans and pasture. This farmer carried a reproductive herd of 65 beef cattle in addition to his crop acres. The east no-till site had a very high water table

Soil Physical and Nutrient Characteristics

Measurements of the soil physical characteristics such as bulk density, wet aggregate strength and dry aggregate size were taken from the east no-till site in 1990 and 1991 (Table 1.31). Though different crops were raised (corn/soybeans) dry soil aggregation was the same for both 1990 and 1991. Fine aggregates of less than 0.25 mm comprised 7% of the sample in 1990 and less than 4% in 1991 (Figure 1.31).

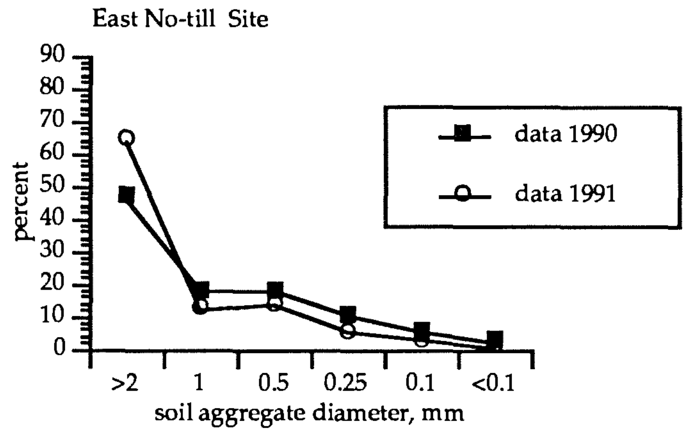


Figure 1.31. Soil aggregate size distribution for the east no-till site; acreage corn in 1990 and soybeans in 1991.

In the east no-till agroecosystem, nitrogen (N) entered the soil through atmospheric precipitation, decomposition of organic matter, application of manure and industrial fertilizer, and N fixation by leguminous crops such as beans. Nitrogen loss in this system occured through crop harvest, volatilization of ammonia, bacterial denitrification and nitrification followed by subsequent leaching.

The farmer of the east no-till site subscribed to a soil testing service. Based on the service's measurement and recommendations, the farmer's experience and management, 60 lbs a^{-1} of 10-50-0 and 2 lbs a^{-1} of zinc (Z) were banded near the corn seed in 1990. The applicator, which applied 48 lbs a^{-1} of anhydrous ammonia followed the drill. The farmer banded 70 lbs a^{-1} of 10-50-0 with 1.52 lbs a^{-1} of Z and 4 ounces of ACA (a fertilizer additive) at seeding for the 1991 crop of soybeans.

Soil tests conducted for this study in the spring and autumn of 1990 and 1991 showed a level of free nitrate, ammonium, and phosphorus (P) to the 48 inch soil depth (Table 1.31). The applications of industrial N was prior to these tests in the spring and were reflected in the amounts. Other soil characteristics measured were pH, organic matter and the lightfraction protion of organic matter (Table 1.31).

Table 1.31. Summary table of soil physical and chemical characteristics for the east no-till site.

Nutrients: Nitrate $mg\ kg^{-1}$	0-3	3-6	6-12	12-24	24-48	Soil Physical Characteristics: Horizon Depth in	Texture	Structure	Carbonates Effervescence	Roots	*Other features
'90 spring	31.69	15.26	10.06	12.89	9.06	Ap 0-13	silt clay	weak SBK	slight	common	
fall	4.09	4.59	5.36	7.12	6.37	AB_k 13-23	clay loam	weak SBK	strong	common	few c.dst.yl. mtles c.dst.gry mtles
'91 spring	3.06	2.60	4.00	5.96	4.23	C_1 24-37	clay	md.SBK	strong	few	md.c.dst.yl.mtles.
fall	5.07	2.78	1.91	3.69	2.50	C_2 38-48	sandy clay loam.	md.SBK	strong	none	md.c.dst.yl. mtles,

Ammonium $mg\ kg^{-1}$	0-3	3-6	6-12	12-24	24-48	**Bulk Density	pH	Organic matter	Light F. $mg\ kg^{-1}$	TKN	N $mg\ kg^{-1}$
'90 spring	47.45	4.87	3.55	7.99	2.38	0.88 cgm^3	7.7	5.10%	760	1.28%	10
fall	2.55	2.77	2.66	1.89	1.95						
'91 spring	5.90	4.59	3.63	3.04	1.66	0.88g cm^3	7.5	7.18%	510	1.32%	7
fall	6.71	5.82	3.77	5.27	3.97						

Phosphorus $mg\ kg^{-1}$	0-3	3-6	6-12	12-24	24-48	Aggregate Stability
'90 spring	9.5	5.0				95%
fall	13.5	4.0				
'91 spring	8.5	5.0				92%
fall	8.5	3.5				

Abbreviations defined:
SBK= subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3;in soils with high rates of organic matter this assumption may be in error.

In addition to the application of industrial N, the nitrogen mineralization and immobilization transformation cycle was affected by factors such as the residual N remaining from the previous year (Table 1.31), the current year's response to climatic factors such as precipitation and temperature and the way in which all of these factors affect the biological system. In an attempt to quantify the effects of these dynamics on soil fauna (bacteria, mites, and springtails) soil cores were extracted to a depth of 15 cm on eight separate days from June to September 1990 (Figure 1.32).

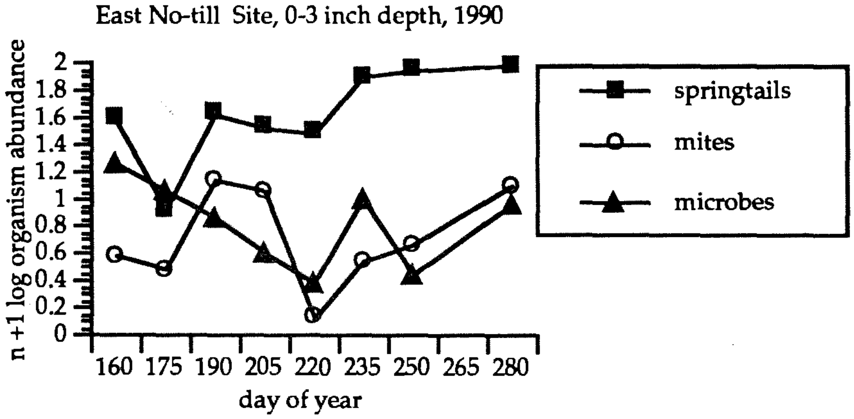


Figure 1.32. Soil fauna population measurements at one soil depth and eight sample dates for 1990. The crop grown on this site was corn. Abundance springtails and mites = 1000 g dw soil; abundance microbes = $mg\ kg^{-1}$ ammonium for 1 g dw soil.

There was no disturbance to the soil on the east no-till site after day of year 128 (May 8) in 1990 but the population of microbes (bacteria) and mites (Figure 1.32) demonstrated great variation in densities throughout the season. Microbe populations were highest in the spring and declined to their lowest point on day of year 220 (August 8) which was also the lowest point for mite population measurements. The mite population peak lasted for two sample dates days of year 190 (July 9) and 205 (July 24). Springtail populations were relatively high throughout the sample period and were consistantly higher than the mites. The lowest population for springtails was on day of year 175 (June 24).

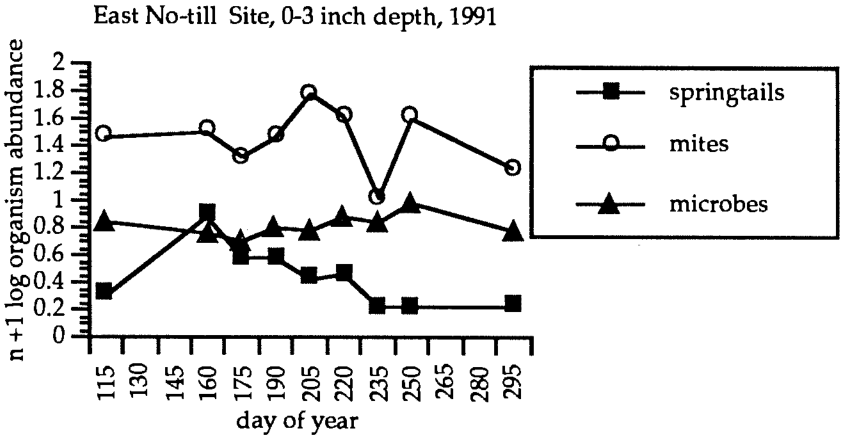


Figure 1.33. Soil fauna population measurements at one soil depth and nine sample dates for 1991. The crop was soybeans. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

In 1991 there were 9 sample dates (Figure 1.33); one earlier and one later than the 1990 season. The microbe activity in 1991 was static for the observation period on this site. Springtail populations were about half the numbers recorded in 1990. The peak population was day of year 160; the lowest points were early spring (day of year 115) and from day of year 235 through the last sample date.

In addition to microarthropods, other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented.

Pitfall traps were collected on 7 sample dates in 1990 and 6 sample dates in 1991 (Figure 1.34). The predominant arthropods collected were as follows: spiders (8 families), beetles (10 families), flies (10 families), and bees (6 families). There was more diversity in 1990. Predominant families of arthropods collected were as follows: daddy longlegs spider *(Phalangida)*, ground beetle *(Carabidae)*, long-legged fly *(Dolichopodidae)*, buffalo gnat *(Simuliidae)*, ants *(Formicidae)*, and crickets *(Gryllidae)*. In addition to these families other arthropods trapped in 1991 were tiger beetle *(Cicindelidae)*, click beetle *(Elateridae)*, and carrion beetle *(Silphid)*.

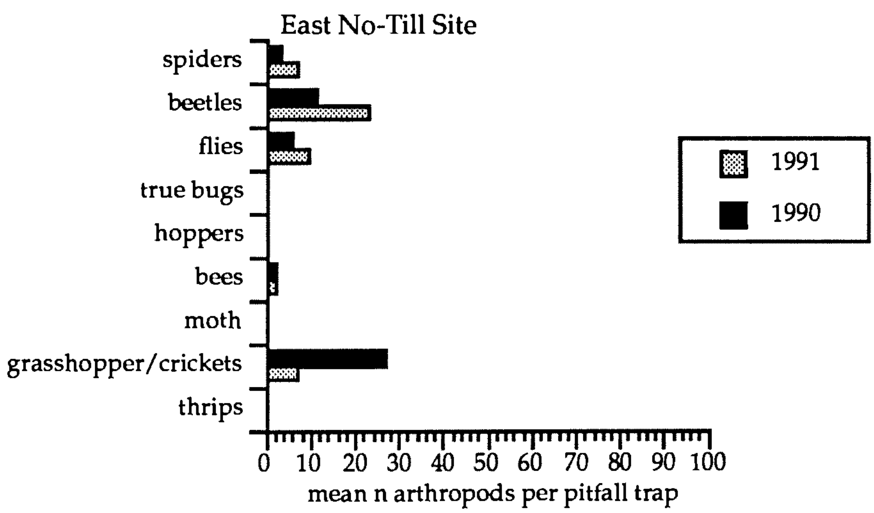


Figure 1.34. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 6 sample dates in 1991. Amounts represent the average number of arthropods for the sample period. Sample size = 12 oz cup set at soil level for 4 consecuative days.

The Margalef index of insect families, an index of quantifying diversity, shows considerable variation in predators and herbivores from one sampling date to the next. This index clearly shows the effects of the insecticides applied at seeding to this system. As the 1990 corn crop progressed the index of herbivore populations increased but the index of predators also increased. It is difficult to interpret the insect diversity measured for the 1991 soybean crop. At day of the year 222, 40 a^{-1} of field margins were sprayed with methyl parathion for grasshopper control.

Table 1.32. The Margalof index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores.

Margalaf Index of Pitfall Trap Insects

East no-till	**Predators**						**Herbivores**					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	1.76	285	3.94	2.54	3.35	3.94	0.18	0	0.38	0.20	1.38	2.16
1991	4.01	3.76	2.82	2.76	3.60	3.38	0.65	0	1.25	0	1.64	0.66
mean	2.89	3.31	3.38	2.65	3.48	3.66	0.42	0	0.82	0.10	1.51	1.41

Plant Species Present

The vegetation present on the east no-till site (Table 1.33) consisted primarily of grasses in 1989 - 1990, and forbs in 1991. The typical crop rotation for this site was oats *(Avena sativa)*, corn *(Zea mays* 'Pioneer 3921 and 3917'), and soybeans *(Phaseolus vulgaris* 'Pioneer 9091'). Green foxtail *(Setaria virdis)* dominated the weed density samples taken in late June, 1990, with an average density of 23 plants per square foot. By mid July the average was 1 green foxtail per square foot. Other weeds present on the early sample date were wild oats *(Avena fatua)* and milkweed *(Asclepias syriaca)* none of these weeds were observed on the July sampling date. Within the 1991 soybean crop, green foxtail was present at the rate of 7.6 plants per square foot in early June, increased to 8.4 plants in late June with no evidence of weeds by late July. Other weeds observed in the soybean crop were milkweed and redroot pigweed *(Amaranthus retroflexus)*.

Table 1.33. Plants present in the east no-till agroecosystem.

East No-till System Species

Zez mays	*Asclepias syriaca*	*Avena fatua*	*Setaria virdis*
Phaseolus vulgaris	*Amaranthus retroflexus*		

Nitrogen uptake by the crop was measured during 1990 and 1991 from clippings taken at physiological maturity. The corn stalk total Kjedahl nitrogen present was 0.83 % whereas the corn grain had 1.70 %. The 1991 soybean straw measured 1.07 % total Kjedahl nitrogen and the grain was 5.80%.

Soil Moisture

Soil moisture (Table 1.34) was determined on this site gravimetrically to a depth of 48 inches during spring and autumn of 1990 and 1991. Precipitation estimates recorded at the nearest weather station during this period totaled 13.52 inches of rainfall for 1990 and 16.8 inches in 1991. Evapotranspiration measurements are a reflection of water used by the crop for net primary production and land use management practices such as row spacing, mulch placement and use of windbreaks. Evapotranspiration from the corn crop was estimated to be 13.21 inches; 13.64 inches for soybeans.

Table1.34. Soil moisture at 0-48 inch sampling depth for spring and fall 1990 and 1991.

	Soil Moisture							
	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.79	0.85	1.60	3.51	6.36	13.11	11.72	13.2
fall	0.64	0.84	2.00	3.24	4.90	11.62		
'91 spring	0.32	0.41	1.24	2.79	4.67	9.43	16.80	13.6
fall	0.58	0.89	1.84	3.66	5.62	12.59		

Management

The objective of no-till farm management is to make as few trips across the field as possible, disturb the stubble mulch as little as possible to control wind and water erosion and maintain or increase production in the process (Proceedings, Conservation Tillage 1990). The 1990 Pioneer 3921 and 3917 corn crop was seeded on May 5th at the rate of 22,000 treated seeds (Maneb-Lindane^{TM} (thiabendazole), drill box 2.75 oz. per bu.) per acre into 32 inch row spacing by a Yielder drill pulled by a Steiger tractor. Row orientation was at an angle to the previous year's planting and a small harrow was attached to the drill to close the macropores that had formed in the field the previous season. Granular fertilizer was banded in the row and anhydrous ammonia was applied on the same drill pass at rate of 46 lbs. a^{-1} of N, 30 lbs. a^{-1} P and 2 lbs. a^{-1} of zinc inputs.

Approximately three weeks after seeding, the field was spot sprayed to control broadleaf weeds ((cyanazine(Bladex ^{TM})@ 4.5 lbs. a^{-1} and dicamba (Banvil^{TM})@ 8oz a^{-1})) with crop oil. One week later the field was treated for cutworm control in the corn ((esfenvalerate (Asana^{TM})@ 6 oz. a^{-1})). This farmer had a small weed sprayer mounted on his combine to spot spray problem areas with glyphosate (Round-up^{TM}12 oz. a^{-1}) as he passed at harvest time.

Uninoculated Pioneer 9091 soybeans were solid seeded on May 6, 1991 at rate of 1.3 bushel a^{-1} (5.8 live plants per square foot) with granular fertilizer banded in the row. Nutrient inputs for the soybean crop were 10 lbs. a^{-1} N, 35 lbs. a^{-1} P, and 4 oz. ACA (a fertilizer additive) per acre.

Two weeks later, the field was sprayed with glyphosate mixed with 2,4-D (4 oz. a^{-1}). Five weeks after seeding, the field was sprayed to control green foxtail, volunteer corn and wild oats ((dfenoxaprop(Option^{TM})@ 1.2 pts.,thigensulfuron (Pinacle^{TM})@ 0.25 oz., and crop oil @ 1 qt. a^{-1})). The spray was not effective in controling the invading grasses; the field was resprayed June 14 (at the chemical company's expense). About 40 acres of field boarder were infested with grasshoppers therefore 4 oz ai a^{-1} of methyl parithion was sprayed on August 10th.

Production and Resource Use Efficiency

The corn was straight combined during mid October. The total net primary production (NPP) for the 1990 corn crop was 16,186 pounds of dry matter per acre and a net grain production of 3580 lbs a^{-1} (farmer field estimate of105 bu a^{-1}); 12,606 lbs a^{-1} of corn stalks and leaves remained in the field. Nitrogen equivalent removed from the field as grain was 61 lbs a^{-1}.

Two weeks prior to harvest in 1991, hail damage to the soybean crop was estimated at 20 percent. The soybeans were harvested in late September with NPP of 11,705 lbs a^{-1} with a net grain production of 4031 lbs. a^{-1} (farmer field estimate of 65 bu a^{-1}); 750 lbs a^{-1} of stems and leaves remained in the field. Nitrogen equivalent removed from the field as grain was 235 lbs a^{-1}.

Using pre-season and post-season soil samples taken to a 48 inch depth, total gravimetric water, nitrate, and ammonium content were determined mathmetically . Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen plus N inputs, production gross nitrogen and water use efficiencies were calculated for 1990 and 1991 crop years (Figure 1.35 and 1.36).

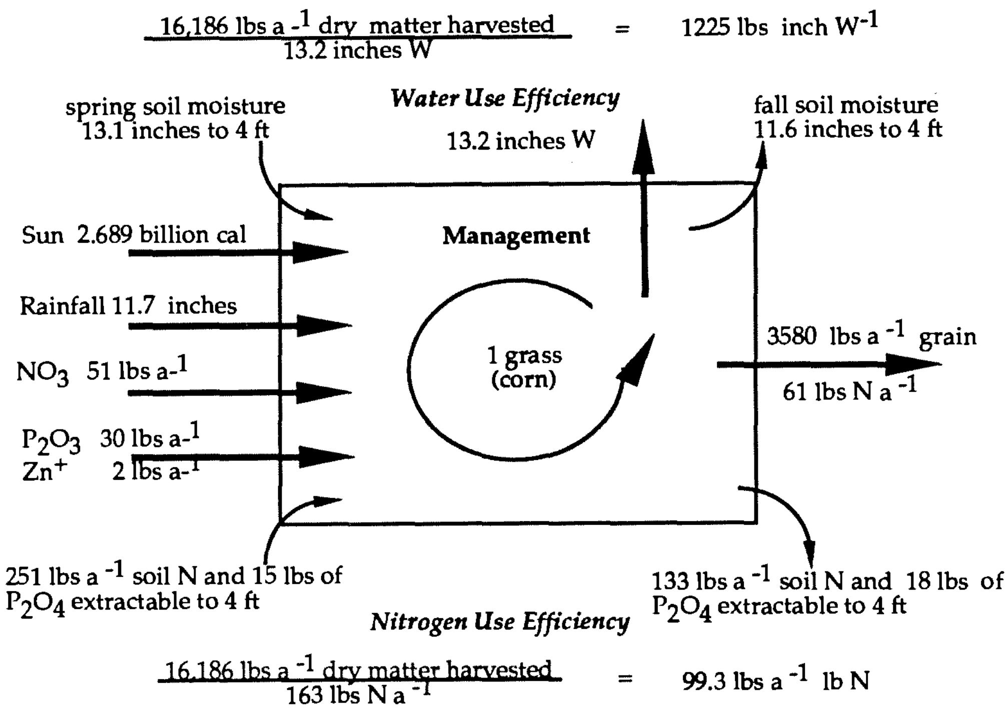


Figure 1.35. Gross inputs, outputs and efficiencies from the no-till site during the summer of 1990. N inputs were incorporated prior to the spring soil tests and are reflected in the 251 lbs a^{-1}.

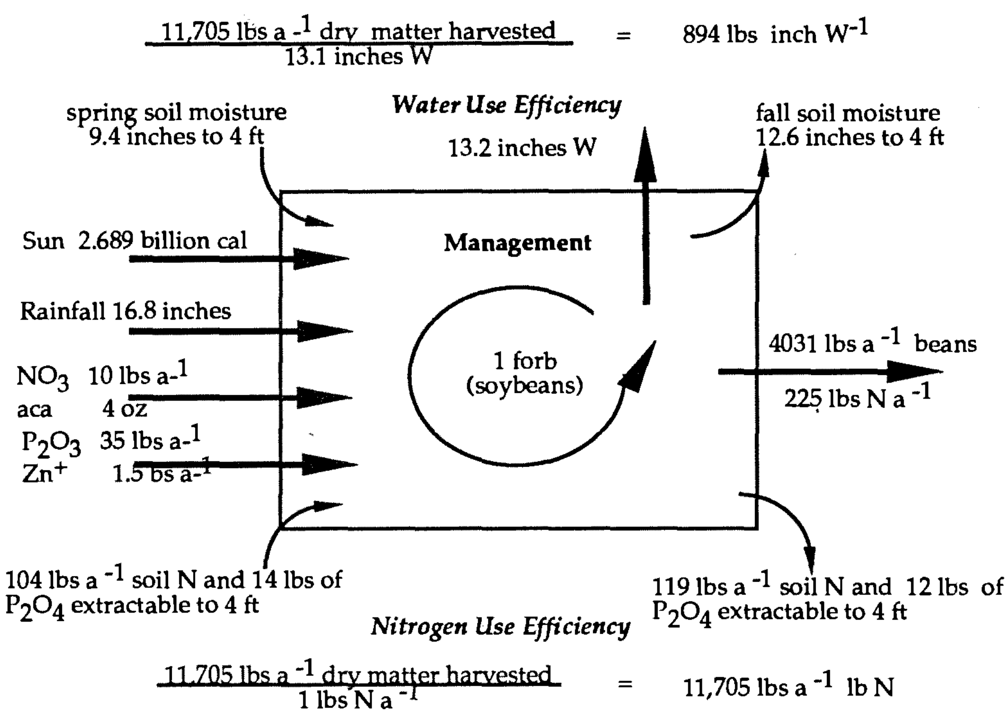


Figure 1.36. Gross inputs, outputs and efficiencies from the the east no-till site 1991. Inputs were applied after the soil tests and were not included in the 104 value.

EAST ORGANIC SITE
Tallgrass prairie ecosystem

Geologic and Social History

Frog Point, the low water point on the Red River, was a commerce site of historical significance during the boom times of trade between Hudson Bay Company and St Paul, Minnesota. It was located in Trail County near the east organic site. The topography of this area was proglacial lake sediment from Lake Agassiz; the materials were of the Coleharbor Group. Elevated topography was limited to low ridges and shallow groves. This topographic relief was the result of the plummeting of floating lake ice and boulders or icebergs dragging bottom in areas of off shore sediment (Bluemle 1977).

Buxton, the farm trade center for the east organic site, was founded by Budd Reeve, a lawyer and real estate agent from Minneapolis. J.J. Hill, the railroad magnet, needed a site for the railroad depot in Minneapolis and Reeve owned the property. Through a series of maneuvers among the railroad insiders, Reeve became the General Manager of the Buxton Corporation. The town of Buxton was founded for the express purpose of bringing a profit to the Minneapolis investors. In addition to Reeve's duties as general manager of Buxton, he founded the Home Builders organization. He based the organization on the theory that the "highest intelligence of country could be brought together to organize for the highest end". He designed the Earth flag (Figure 1.41) which was to represent a rainbow promising unity of mankind to build a democracy on the foundation of natural law. Black represented soil, green - vegetation, yellow- harvest, red-the blood of man, and white- strength and cleanness of character. The gold star in a white field was to represent the commonality of all nations (Hauge 1980). The railroads also brought the European settlers. Some of whom came to be part of a Bonanza farm while others filed their own claims.

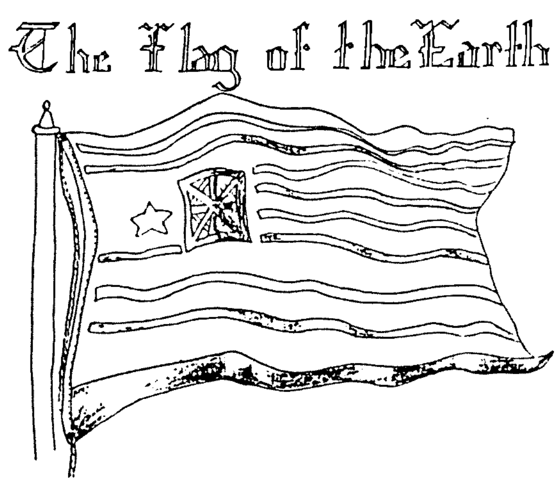


Figure 1.41. Earthflag designed by Budd Reeve for the Home Builders Club. It flew over Buxton from 1907 until it was in shreds.

The present owner's ancestors emigrated from southern Minnesota to work on a farm in Minot. As the family patriarch traveled across the Red River Valley, he noted the enormous straw piles that remained after thrashing. This vision prompted his dream of owning Red River Valley land. In ten years he had saved enough to purchase the land near Frog Point. He realized his dream in 1934 - with one dime to spare. He placed this dime on a window sill as a reminder that as tough as the 1930's were he was not broke. Legumes in rotation and green manure plow-down were a part of his farm management style along with cover cropping and field windbreak practices. The second generation took over management of

the farm in 1970. The present farmer's wife came from a Minnesota dairy farm where no chemicals were used and fertilizer was applied only sparingly.

Since dry beans are a leguminous crop and it was a family tradition to raise legumes without additional inputs, raising beans organically was not a new technique for him. On the suggestion of a neighbor, this farmer attended a meeting of the Northern Plains Sustainable Agriculture Society convened in Fargo. It was at this meeting in the early 1980's that he met with buyers interested in purchasing organically grown beans for a premium price. The farmer and his wife realized that organic farm management techniques meshed with their current farming practices and philosophy.

The sampling regime on the east organic site consisted of an in-depth evaluation of a level, one acre portion of a 79 acre field. The index soil, Beardon as classified by a soil scientist of the Soil Conservation Service of USDA (Table 1.41), was a silt clay loam. With the exception of some areas in the township where there were soils found on ridges formed by glacial ice, the whole quarter section of land would be of the same soil type. Once covered with native vegetation of tallgrass species, this farm was under the production of small grains (HRS wheat, durum, barley, and oats), 6 types of beans (kidney, Navy, black, garbanzo, Swedish brown, and pinto), green field peas, popcorn and alfalfa. The choice of crop depended upon the condition of the land, the anticipated weather, and the potential market for that season.

Soil Physical and Nutrient Characteristics

Measurements of the soil physical characteristics such as bulk density, wet aggregate strength and dry aggregate size were taken from the east organic site in 1990 and 1991 (Table 1.41).. Fine dry aggregates smaller than 0.25 mm comprised less than 8 % in 1990 and 9 % in 1991 (Figure 1.42).

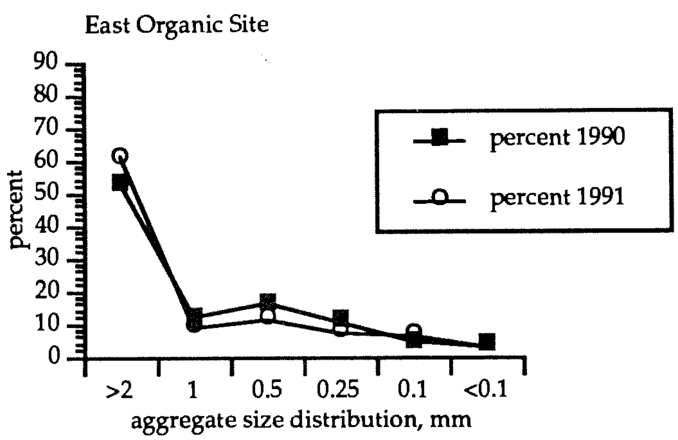


Figure 1.42. Soil aggregate size distribution for 1990 and 1991 alfalfa acreage.

In this organic farm agroecosystem, nitrogen (N) entered the soil through atmospheric precipitation, decomposition of organic matter, and nitrogen fixation by leguminous crops such as alfalfa and beans. Nitrogen loss in this system occurred through crop harvest, volatilization of ammonia and bacterial denitrification, and nitrification followed by subsequent leaching.

There were no commercial N inputs to this farm system. Soil tests conducted in the spring of 1990 showed 120 pounds per acre of free nitrate and ammonium at the 48-inch soil depth. The autumn test revealed 73 lbs a^{-1} remaining after harvest of two hay crops. The 1991 autumn N levels in the top 3 inches were higher than the previous year. Alfalfa was plowed down prior to this sample period (Table 1.41).

Table 1.41. Summary table of soil physical and chemical characteristics for the east organic site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	4.21	5.21	6.70	4.58	3.57
fall	1.65	2.33	1.74	2.19	1.82
'91 spring	2.16	2.03	1.65	0.63	0.43
fall	3.63	2.17	1.33	0.50	0.49
Ammonium mg kg^{-1}					
'90 spring	3.69	3.35	3.15	2.26	3.41
fall	2.74	2.90	2.76	2.83	2.97
'91 spring	7.65	4.37	3.42	2.79	2.12
fall	5.80	3.55	2.58	2.17	2.43
Phosphorus mg kg^{-1}					
'90 spring	6.5	5.5			
fall	4.5	4.0			
'91 spring	4.5	4.0			
fall	5.0	3.5			

Soil Physical Characteristics

Horizon Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A 0--9	silt clay loam.	md.SBK parting to gran.	slight	many fine	
AB_k10-15	silt clay loam.	md SBK	violent	common	
B_k16-24	silt lay loam.	weak SBK	violent	few	
$C_1$25-39	silt loam	weak SBK	strong	fnone	md..c.gry. and yl. mtles.
$C_2$40-48	silt clay	massive	strong	none	md.c.yl.mtles.few gry.mtles few thrds .carbonates and Fe

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
1.07g cm^3	8.0	3.74%	925	1.62%	15
0.96 g cm^3	7.9	5.54%	1105	1.02%	114

Aggregate Stability
73%
89%

Abbreviations defined:
*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

TKN Kjedahl nitrogen tests revealed 2.50, 1.35,1.27 and 0.60 nitrogen for alfalfa, standing dead material, litter, and weeds, respectively. Translated into pounds of nitrogen per acre this resulted in 13 lbs for alfalfa, 3.6 lbs for standing dead material, 24.8 lbs for litter, and 0.3 lbs for weeds. The estimated plow down nitrogen for above ground plant materials was 41.7 pounds. Other soil physical and chemical soil parameters measured on this site include pH, organic matter and the lightfraction component of organic matter (Table 1.41).

The nitrogen mineralization and immobilization transformation cycle was affected by factors such as the residual nitrogen remaining from the previous year (Table 1.41), the current year's response to climatic factors such as precipitation and temperature, and the way in which all of these factors affected the biological system. Organic matter from the beans/oats/alfalfa/alfalfa rotation were the substrate for the mineralization process in the below ground food web. In an attempt to quantify the effects of these dynamics on soil fauna (bacteria, mites and springtails), soil cores were extracted to a depth of 15 cm on eight separate days from June to September 1990 (Figure 1.43).

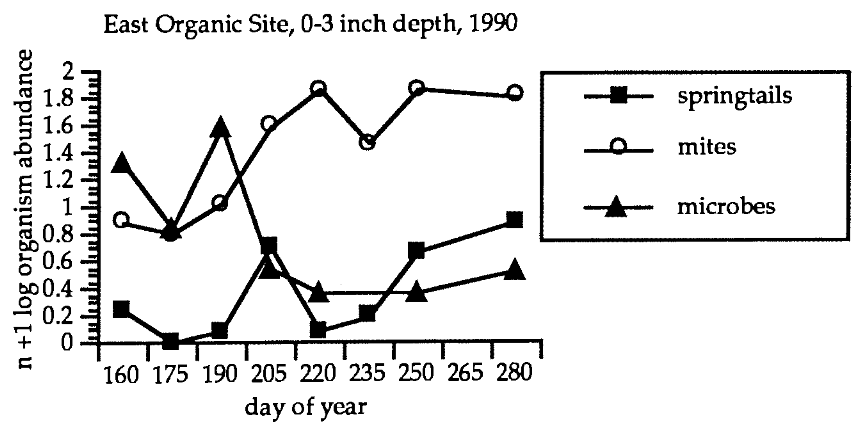


Figure 1.43. Soil fauna population measurements at one soil depth and eight sample dates for 1990. The crop grown on this site was alfalfa. Abundance springtails and = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

Mite populations in 1990 rose until mid-August (day of year 220) and remained relatively high through the autumn. Microbe populations peaked in the early part of the growing season, day of year 190 (July 10) and were at their lowest point by mid-August with a tendency to increase toward fall. Springtail populations tended to be lower in relation to the other organisms quantified. Population dynamics for springtails, mites, and microbes reveal a curve of steep hills and valleys (Figure 1.43).

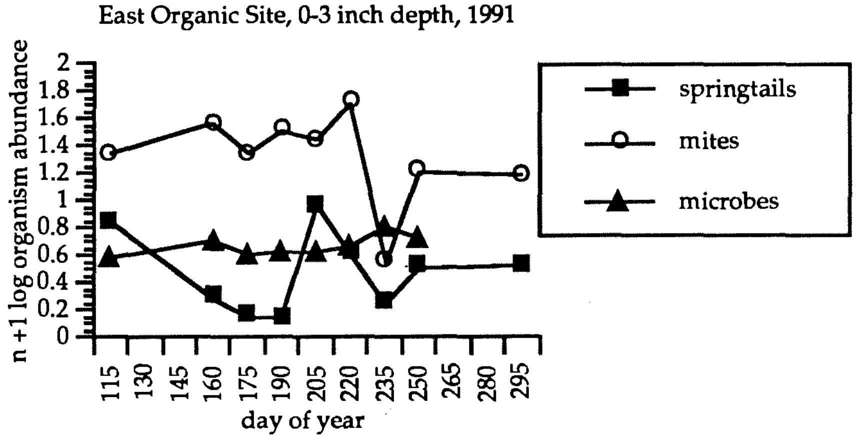


Figure 1.44. Soil fauna population measurements at one soil depth and nine sample dates for 1991. The crop was alfalfa. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

Microbe populations were rather flat through the 1991 (Figure 1.44) growing season. Springtail and mite populations showed a sharp decline after the alfalfa was swathed and combined on days of year 224 (August 12) and 227 (August 15), respectively. The effects of plowing on day of year 259 and disking on day of year 270 were not dected by the study's sampling intervals. Springtail population peaked on day of year 115 (April 25) and 205 (July 24); the lowest measurements extended through two sample dates--days of year 175 (June 24) and 190 (July 9). Mite populations were relatively high throughout the growing season.

In addition to microarthropods, other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented.

Pitfall traps were collected on seven successive sample dates in 1990 and five sample dates in 1991 (Figure 1.45). The predominant arthropods collected for 1990 and 1991 were as follows: spiders (7 families), beetles (11 families), flies (7 families), bees (7 families), and crickets.

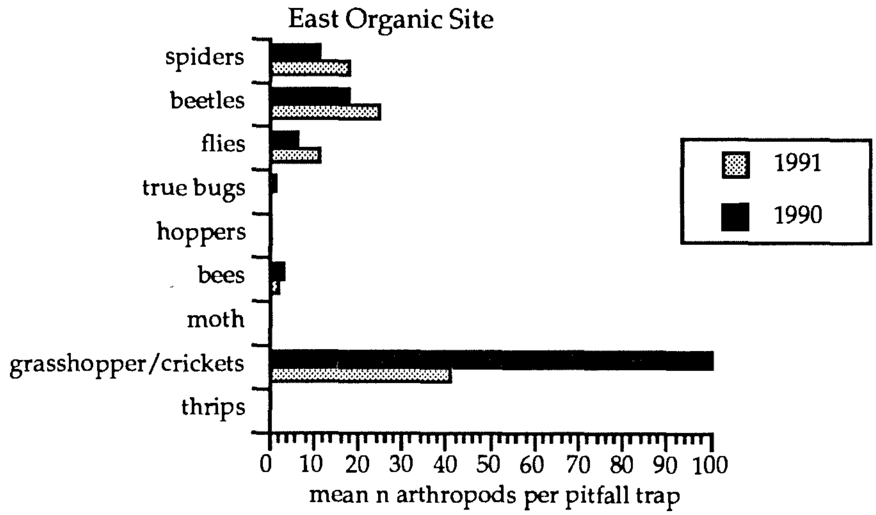


Figure 1.45. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 5 sample dates in 1991. Amounts indicate the average number of arthropods per trap for the total sampling period. Sample size = 12 oz cup set at soil level for 4 consecutive days.

The predominant families of arthropods trapped in 1990 were daddy longlegs *(Phalangida)*, ground beetle *(Carabidae)*, click beetle *(Elateridae)*, carrion beetle *(Silphidae)*, buffalo gnat *(Simuliidae)*, scentless plant bug *(Rhopalidae)*, small metalic burrowing bees *(Halicitdae)*, common sawfly (*Tenthredinidae*), and crickets *(Gryllidae)*. In 1991 the predominant arthropods trapped were as follows: daddy longlegs, wolf spiders (*Lycosidae*), ground beetles, carrion beetles, buffalo gnats, leaf cutting bees *(Megachilidae)*, and crickets.

The Margalef index is an index of diversity. In this study it was used to test the diversity of insect families of predators and herbivores. The higher the number the greater the diversity.

Table 1.42. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores.

Margalef Index of Pitfall Trap Insects

East organic	**Predators**						**Herbivores**					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	3.61	1.06	2.02	2.74	2.96	2.72	0	0.20	0.32	0.22	1.20	0.84
1991	6.82	3.00	1.86	3.58	3.60	M	1.32	0.22	0.14	1.50	2.16	M
mean	5.22	2.03	1.94	3.16	3.28	2.72	0.66	0.21	0.23	0.86	1.68	0.84

Plant Species Present

The vegetation present (Table 1.43) on the east organic site consisted primarily of alfalfa *(Medicago sativa)* in 1990 and 1991. The typical crop rotation for this site was beans *(Phaseolus vulgaris)*, oats *(Avena sativa)* and alfalfa/alfalfa. Green foxtail *(Setaria virdis)* dominated the weed density samples taken with an average density of 23 plants per square foot (about 12 percent of cover) by mid-July to less than 3 percent of the cover by August.

Table 1.43. Plants present in the east organic agroecosystem.

East Organic System Species		
Meciago sativa	*Setaria virdis*	*Cirsium vulgar*

Nitrogen uptake by plants was measured during 1990 and 1991 from clippings taken monthly during the growing season. The alfalfa at peak production measured 2.97 percent, at harvest 2.70 percent for 1990. Plant tissue nitrogen for 1991 measured lower with 2.60 percent for alfalfa at peak production, and 2.36 percent at harvest in August. TKN measurements from the plow-down sample of standing dead material were 1.35 percent and 1.27 percent for litter.

Soil Moisture

Soil moisture (Table 1.44) was determined on this site gravimetrically to a depth of 48 inches during spring and autumn. Precipitation estimates recorded at the farm during this period totaled 9.9 inches of rainfall for the 1990 growing season. Water use measurements for 1990 were estimated to be 13.5 inches. Rainfall for the 1991 growing season was 16.6 inches and water use estimates were 15.9 inches for alfalfa.

Table 1.44. Total soil moisture at 0-48 inch sampling depth for spring and fall 1990 and 1991.

	Soil Moisture							
	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.48	0.73	1.48	2.69	5.03	10.41	9.87	13.5
fall	0.42	0.53	1.04	1.61	3.19	6.79		
'91 spring	0.61	0.91	1.63	1.92	4.06	9.13	16.58	15.9
fall	0.46	0.69	1.04	1.95	5.71	9.85		

Management

The objective of an organic farm management system is to use natural soil-building routines and crop rotation schemes instead of synthetic inputs to supply nutrients, control weeds, insects, and disease in the production of agronomic crops and livestock (Kirschenmann 1988). Beginning with 1988, the crop rotation on the east organic site was beans/oats/alfalfa/ alfalfa. The alfalfa acreage used for this study was sown (12 lbs a^{-1}) in early spring of 1989 with oats used as a nurse crop. A seedbed was prepared for oats using the field cultivator; oats were seeded the next day. Other field operations for the oats crop were swathing and combining in late July.

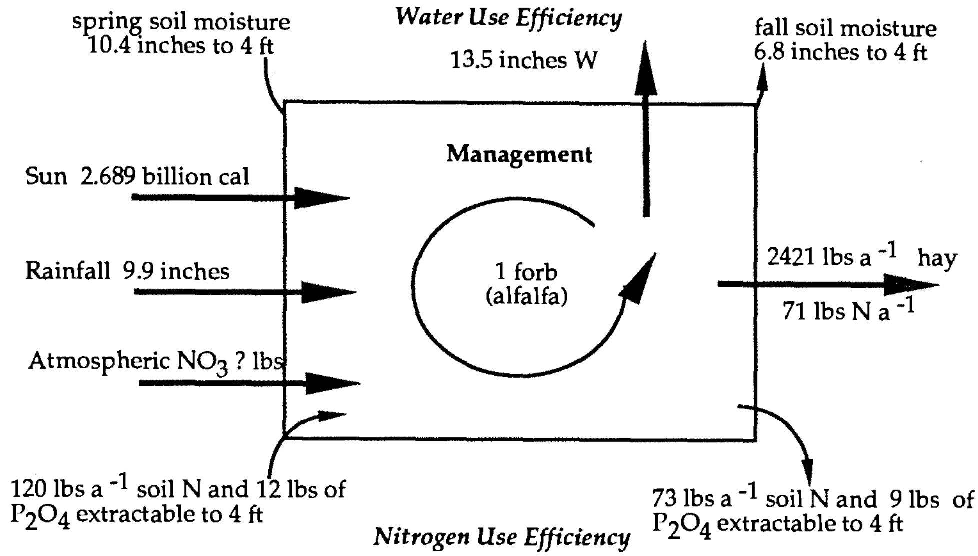
The field was plowed in mid-September of 1991 and disked at the end of the month. The net primary production turned under was 2900 lbs a^{-1} mostly in the form of litter. The nitrogen content was 41.7 lbs a^{-1}.

Production and Resource Use Efficiency

Alfalfa was cut twice for hay in 1990. A five-inch stubble remained each time. Harvesting occurred in late June and early August, yielding a combined harvested primary production of 2421 lbs a^{-1} dry weight with an estimated 71 lbs a^{-1} of N removed. The net primary production (NPP) dry matter measured at peak for the 1990 alfalfa crop was 3332 lbs a^{-1}. The 1991 crop was swathed and combined for seed in mid-August yielding an estimated 12.5 lbs a^{-1} of seed. Leee than 1 lb a^{-1} N was removed. The NPP for the 1991 alfalfa crop was 2239 lbs a^{-1}.

Using pre-season and post-season soil samples taken to a 48-inch depth, total gravimetric water, nitrate, and ammonium content were determined mathematically. Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen plus N inputs from the alfalfa, plow-down gross nitrogen and water use efficiencies were calculated for 1990 and 1991 crop years (Figures 1.46 and 1.47).

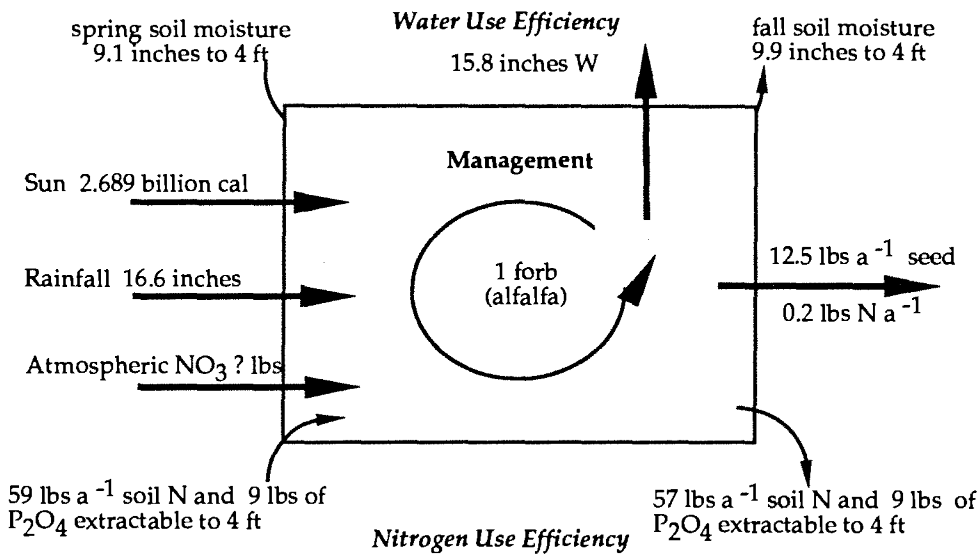
$$\frac{3332 \text{ lbs a}^{-1} \text{ dry matter harvested}}{13.5 \text{ inches W}} = 247 \text{ lbs inch W}^{-1}$$



$$\frac{3332 \text{ lbs a}^{-1} \text{ dry matter harvested}}{49 \text{ lbs N a}^{-1}} = 68 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 1.46. Gross inputs, outputs, and efficiencies from the east organic site during the summer of 1990.

$$\frac{2239 \text{ lbs a}^{-1} \text{ dry matter harvested}}{15.9 \text{ inches W}} = 141 \text{ lbs inch W}^{-1}$$



$$\frac{2239 \text{ lbs a}^{-1} \text{ dry matter harvested}}{2 \text{ lbs N a}^{-1}} = 1120 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 1.47. Gross inputs, outputs, and efficiencies from the east organic site during the summer of 1991. Autumn N amounts reflect sampling after the plow-down of alfalfa.

CENTRAL PRAIRIE SITE
Mixed grass prairie ecosystem

Geologic and Social History

The central prairie site was located in the north central portion of Stutsman county and was geologically part of the glacial plains region. Glacial sediment from the Coleharbor group was an unsorted mixture of clay, silt and sand deposits rising 150 feet above the James River bed creating a rolling landscape including a few potholes and hills. The James River, a tributary of the Missouri, flows over bedrock in a route established by the margin of the glacier (Winters 1963, Bluemle 1977). The river valley partly filled with drift dammed the stream to form the series of shallow melt water channel lakes of Arrowood, Mud, and Jim lakes (Willard 1902).

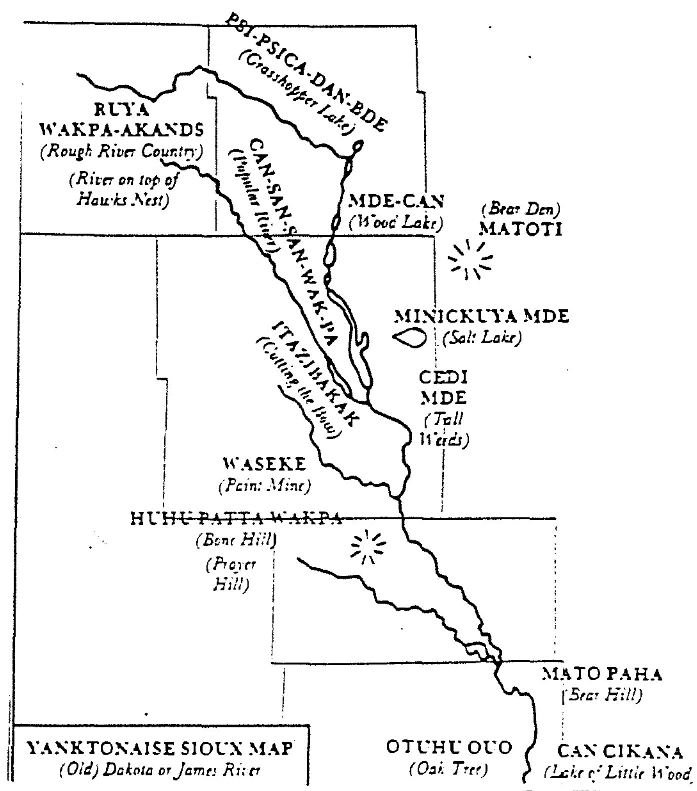


Figure 2.11. Yanktonaise Sioux map extending through Wells, Foster, Stutsman, Lamoure and Dickey Counties. The arrow marks the location of the central prairie site.

The lands, originally part of the Yanktonaise Sioux Indian hunting territory (Figure 2.11), were settled by European Americans in 1871. The James River was the route connecting Fort Seward to the Devils Lake Indian agency and "Limpy Jack" Clayton's dugout shelter was the resting point at the south end of Arrowood Lake (Smorada et. al. 1983).

William Riebe came to Stutsman county from Minnesota to farm the quarter section of land on the west bank of the James River opposite Limpy Jack's road house. After several years, William physically abandoned his family leaving Hugo, his eldest son, to manage the farm with his brothers.

In 1925 Hugo Riebe contacted his friends and neighbors to garner support to make a state park of 63 acres of school lands. By 1935 these lands plus 15,871 additional acres were

dedicated to the US Dept of the Interior for the purpose of attracting waterfowl during the spring and fall migration periods and to develop nesting habitat for breeding grebes, shorebirds and upland game birds.

W. C. Hayland who owned a dance pavilion (Limpy Jack's roadhouse) near the old settlers picnic grounds (Hugo Riebe's state park), moved away when the federal government bought the land. "Grover and Theodore Riebe experienced what to them was an agonizing time dealing with the government when the Arrowood Wildlife Refuge was created in 1935" (Smorada et. al. 1983).

In May of 1934, The Foster County Independent report from Arrowood stated that the farmers were disheartened. The small grain had been blown out of the ground by the dust storms that were raging day after day without rainfall. The wells were going dry, farm auctions were common-place and those attending refused to bid on "anything that eats". It was a time of searching for ideas that could be implemented immediately to alleviate the "severe" needs of the people. In February of 1934 two NDAC (now NDSU) professors proposed that the government set aside marginal lands for the propagation of wildlife (FCI 2/22/1934).

On a trip through the state in August of 1934, President Franklin Delano Roosevelt stopped at Devils Lake where he promised he would do something for the drought ridden state (FCI 9/6/34). In January of 1935 plans were announced to purchase James River land; in February the rules for land use were outlined and in March the bids were opened for the construction of the dams, buildings and fencing for the new migratory waterfowl refuge at Jim and Arrowood Lakes(FCI 1/3, 2/21, and 3/21/1935).

A portion of the Arrowood National Wildlife Refuge prairie was used as a standard for comparison with the other farms in this study that are also located in the mixed grass prairie region of central North Dakota. The sampling regime consisted of an indepth evaluation of a level, one acre portion of the 20 acre central prairie site. The Svea soil type (Table 2.11, soil physical characteristics) was used as the reference soil for all the sites that were evaluated in central North Dakota and was verified by a soil scientist from the Soil Conservation Service of the USDA.

Once covered with native vegetation of mixed grasses in transition between tall grass species and western short grasses (Bluemle 1965), the homesteaders plowed the prairie for small grain production. Because these acres were a part of a government plan to set aside marginal lands for the propagation of wildlife in the mid thirties, they were seeded back to native and tame grass species at that time.

<u>Soil Physical and Nutrient Characteristics</u>

Measurements of the soil physical characteristics such as bulk density, wet aggregate strength and dry aggregate size were taken from the central prairie site in 1990 and 1991 (Table 2.11). Fine aggregates of less than 0.25mm were 9% in 1990 and 3% in 1991 (Figure 2.12).

Table 1.21. Summary table of soil physical and chemical characteristics for the central prairie site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	8.31	5.35	4.69	3.26	2.35
fall	2.35	1.75	2.35	2.50	2.31
'91 spring	1.56	1.33	0.53	0.33	0.04
fall	2.20	1.29	0.61	0.30	1.67
Ammonium mg kg^{-1}					
'90 spring	5.29	3.34	3.37	3.10	2.08
fall	2.93	2.37	1.91	2.28	1.98
'91 spring	8.46	5.37	3.28	3.39	2.08
fall	6.54	4.24	2.73	1.82	2.19
Phosphorus mg kg^{-1}					
'90 spring	9.5	6.0			
fall	8.0	4.0			
'91 spring	8.0	4.0			
fall	8.0	4.0			

Soil Physical Characteristics

Horizon	Depth in	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A	0-8	loam.	gran	neutral	many	
B_{w1}	8-16	clay loam.	weak SBK	neutral	common	
B_{w2}	17-25	clay loam.	weak SBK	neutral	common	
B_k	26-34	loam	weak SBK	strong	few	c.md..yl. mtles.
C_1	34-41	sandy clay loam	massive	strong	none	c. fine yl. mtles.
C_2	42-48	clay loam	massive	strong	none	c. fine yl.mtles.

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
0.99g cm^3	7.5	5.28%	14,156	1.13%	185
0.97g cm^3	6.7	6.67%	1020	0.96%	10

Aggregate Stability
97%
95%

Abbreviations defined:

*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.

**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

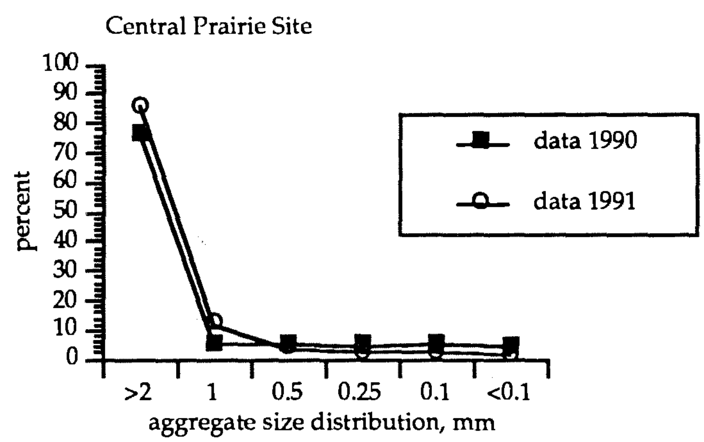


Figure 2.12. Dry soil aggregate size distribution for 1990 and 1991.

In a mixed grass prairie, nitrogen enters the soil through atmospheric precipitation, release of organically bound nitrogen attached to particulate matter and nitrogen fixation by bacteria and blue green algae. Nitrogen exits the system through volatilization of ammonia, bacterial denitrification and nitrification followed by subsequent leaching.

In an attempt to trace the fate of nitrogen in the system, soil tests were conducted in the spring and autumn (Table 2.11). In addition, nitrogen was monitored in a portion of the soil organic matter and plant parts (i.e., leaves, stems, and seeds) throughout the growing season (Figure 2.13). Data from this prairie site indicated that both free nitrate and ammonium existed in low concentrations. Of the two year sampling period nitrate levels were highest in the spring of 1990 following grazing. The ammonium levels for 1991 were higher than nitrate in both the spring and autumn (Table 2.11). Phosphorus levels in the plow layer were tested in spring and autumn both years of the study and were highest at the 0-3 inch depth (9.5 lbs a^{-1}, Table 2.11) for the 1990 sampling regime.

The nitrate-ammonium relationship in the native prairie ecosystem is tightly bound within a nitrogen mineralization and immobilization transformation cycle. Organic matter from the

prairie plant residues were the substrate for the mineralization process in the below ground food web. From the spring sample, the lightfraction component of soil organic matter was extracted. The sharp difference in the values (Table 2.11) for the two years of tests was attributed to the drought which preceded the spring 1990 tests.

Nitrogen uptake by plants was measured in vegetative clippings taken at four times during the season (1991 data presented in Figure 2.13). The nitrogen content of the above ground plant material depended upon age and component (i.e. forbs, litter, etc.). Within a single season the nitrogen concentration decreased by autumn.

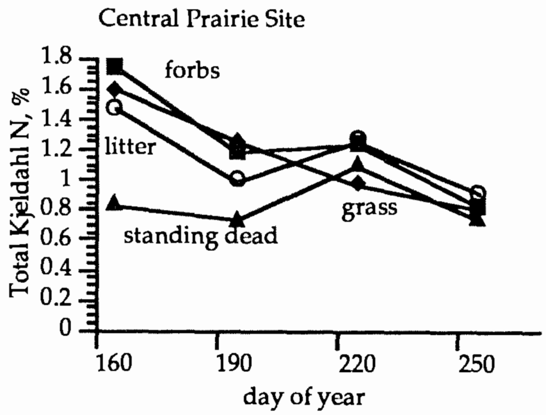


Figure 2.13. Total Kjeldahl nitrogen,% present in above ground biomass at the mixed grass prairie site during 1991.

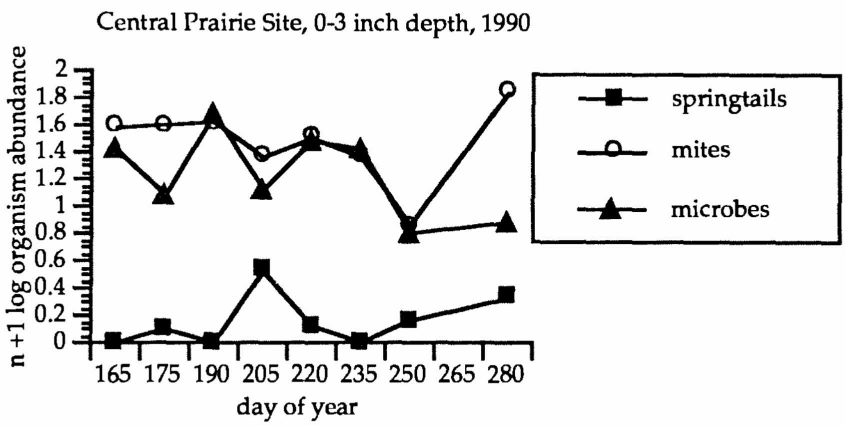


Figure 2.14. Soil fauna population measurements at one soil depth and eight sample dates for 1990. The crop was mixed grass prairie. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1g dw soil.

Activity of the soil fauna on the central prairie site was quantified by extractions made from soil cores taken on eight separate sample dates from June to September 1990 (Figure 2.14). The population of microbes (bacteria) were the highest for day of year 190 (July 9th) and lowest for days of year 250-280 (September 7th to October 7), the last sample date for this observation period. -Springtails were at their peak on day of year 205 (July 24). Springtail populations tend to increase in the autumn but over the season their numbers are the lowest of the fauna quantified. The mite population was highest in the spring, days of year 160 -190 (June 6th -July 9th) and again in the autumn on day of year 280 (October 7th).

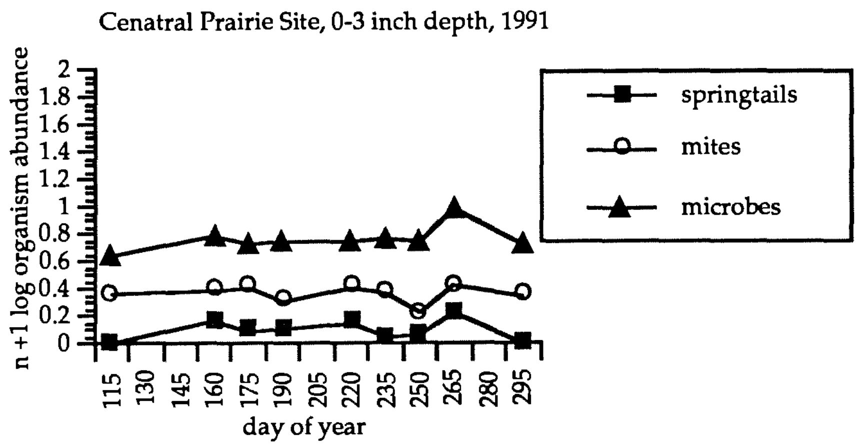


Figure 2.15. Soil fauna population measurements at one soil depth and nine sample dates for 1991. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg $^{-1}$ ammonium for 1g dw soil.

In 1991 soil cores were taken on 9 sample dates from April to October (Figure 2.15). The soil fauna activity was static for the 1991 observation period on this site; there was an abundance of rainfall and little disturbance. The highest population numbers were recorded on day of year 265 (September 22).

In addition to microarthropods other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented.

Pitfall traps were collected on 7 successive sample dates for 1990 and 6 sample dates in 1991 (Figure 2.16) The predominant arthropods collected were as follows: spiders (9 families), beetles (9 families), flies (10 families), bees (8 families), moths (4 families), grasshoppers and crickets. The wolf spider *(Lycosida)*, carrion *(Silphidae)* and ground beetles *(Carabida)*. buffalo gnats *(Simuliidae)* and long legged flies *(Dolichopodidae)*, stink bugs *(Pentatomidae)*, leaf hoppers *(Cicadellidae)*, ants *(Formicidae)*, and ghost moths *(Hepialidae)* comprised most of the pitfall trap organisms quantified in 1990 and 1991.

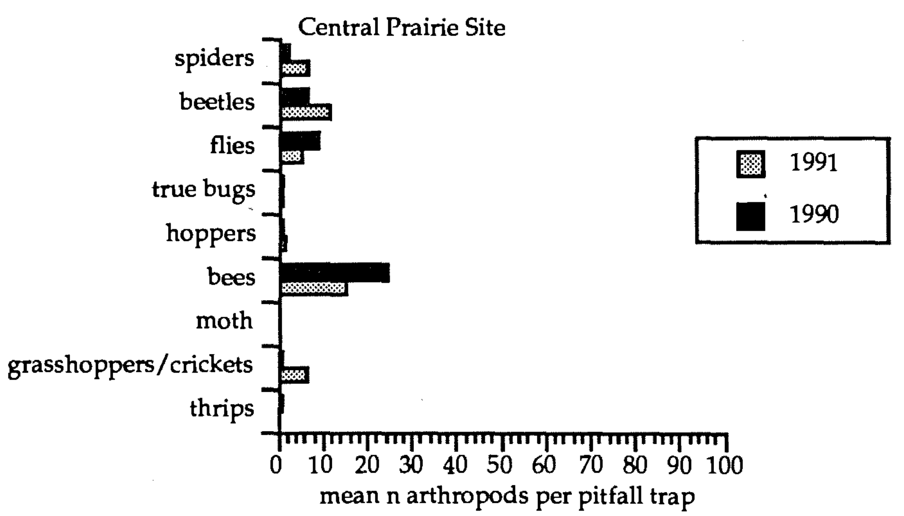


Figure 2.16. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 6 sample dates in 1991. Numbers are the mean arthropods for the sample period. Sample size =12 oz cup set at soil level for 4 consecuative days.

The Margalef index is a measurement of diversity. The test was applied to insect families across time to determine the diversity of predators and herbivores. The diversity of predators remained relatively constant across time.

Table 2.12. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores.

Margalef Index of Pitfall Trap Insects

Central prairie	Predators						Herbivores					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	2.96	3.66	3.72	3.88	4.16	3.28	1.14	1.86	0	0	1.16	0.32
1991	5.94	5.92	4.36	4.80	2.96	4.60	2.20	0.66	1.22	0.78	0	1.32
mean	4.45	4.79	4.04	4.34	3.56	3.94	1.67	1.26	0.61	0.39	0.58	0.82

Plants Present

The vegetation present (Table 2.13) on the mixed grass prairie site consisted primarily of grasses and forbs. A total of four grasses, ten forbs, and one woody shrub were present on this site. Since the land had been cultivated prior to 1935, the plant species present represent a planted prairie site of cool season sod forming grasses and clover. Intermediate wheatgrass *(Agropyron intermedium)*, western wheatgrass *(Agropyron smithii)* and smooth brome *(Bromus inermis)* were planted and have subsequently been invaded by Kentucky blue grass *(Poa pratensis)* to the extent that the blue grass comprised 53% of the vegetative cover. Nitrogen producing Alsike clover *(Trifolium hybridum)* was the most abundant forb present. Buckbrush *(Symphoricarpos albus)*, a woody shrub, comprised 3.8% relative density.

Table 2.13. Plants present in the central prairie site.

Central Mixedgrass Prairie Species

Agropyron intermedium	*Antennaria parvifolia*	*Glycyrhiza lepidota*
Agropyron smithii	*Artemisia ludoviciana*	*Psoralea lanceolata*
Bromus inermis	*Asclepias syriaca*	*Solidago nemoralis*
Poa pratensis	*Astraglus flexuosus*	*Solidago rigida*
Ambrosia psilstachya	*Cirsium arvense*	*Trifolium hybridum*
		Symphoricarpos albus

Soil Moisture

Soil moisture (Table 2.14) was determined gravimetrically to a depth of 48 inches during spring and autumn. Precipitation estimates recorded at the nearest weather station during this period totaled 14.31 inches of rainfall for 1990 and 19.97 inches for 1991.

Table 2.14. Soil moisture at 0-48 inches sampling depth for spring and fall 1990 and 1991.

Soil Moisture

	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.89	0.89	1.53	2.17	3.07	8.55	14.31	19.24
fall	0.38	0.35	0.52	0.99	1.38	3.62		
'91 spring	0.17	0.26	0.35	0.36	0.72	1.86	19.97	15.84
fall	0.38	0.58	1.07	1.44	2.88	6.35		

Management

Management objectives on the central prairie site were to allow maximum utilization of the uplands by waterfowl, upland gamebirds, and other ground nesting birds by providing optimum native plant material for nest sites, food and winter cover for both resident and

migratory wildlife. Rotational high intensity short durational grazing by livestock was used as a maintenance treatment.

The central prairie site was grazed in 1989 at the rate of 1.5 AUM a^{-1} for 15 days initiated on June 15th after the various game bird hens had initiated setting. The higher than customary stocking rate was used to entice the livestock to eat the standing dead material. The grazing program was monitored to adjust grazing and length of rest for the pasture to produce desired changes in the native plant community (ANWR 1989).

Production and Resource Use Efficiency

There was no grazing on the central prairie site during the duration of this study, 1990 and 1991. Biomass samples were taken monthly to determine peak production and net primary production (NPP). During the 1990 growing period (Figure 2.17) 2620 lbs a^{-1} of dry matter was produced with a net nitrogen soil loss of 16 lbs a^{-1}. For 1991, soil tests determined a net gain of soil N after production of 4329 lbs a^{-1} of dry matter with 33 lbs a^{-1} of N stored in the grass, forbs, standing dead and litter (Figure 2.18).

Using pre-and post-season soil samples taken to a 48 inch depth, total gravimetric water, nitrate, ammonium, and phosphorus content were determined. Coupled with locally recorded precipitation amounts and an undetermined amount of atmospheric and legume nitrogen input, gross nitrogen and water use efficiencies were calculated (Figure 2.17 and 2.18).

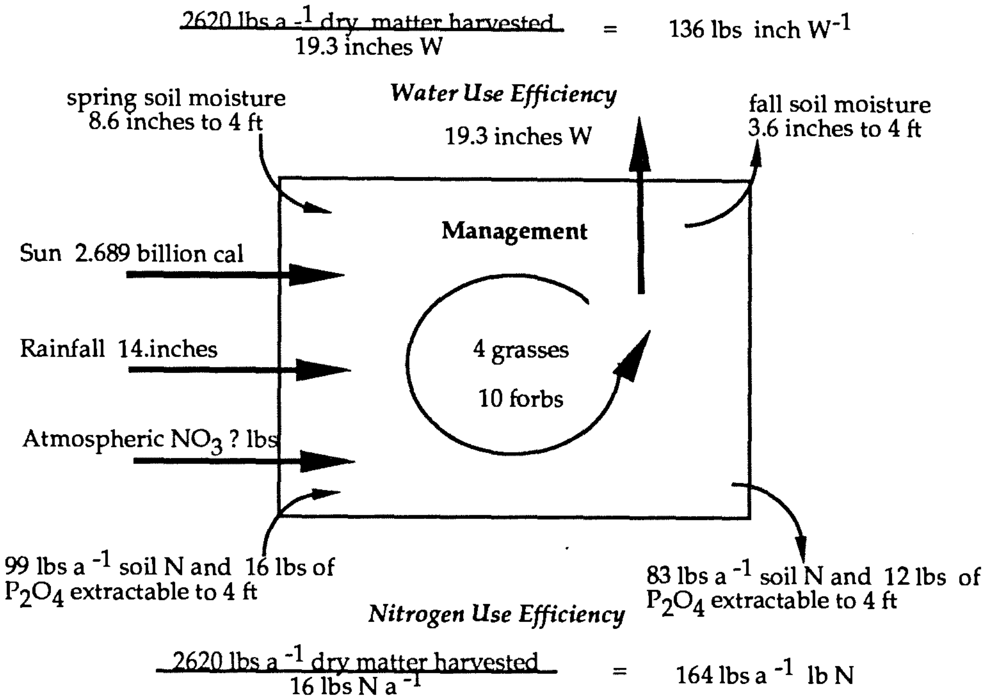


Figure 2.16. Gross inputs, outputs, and efficiencies from the central prairie site during the summer of 1990. In June three heavy rainfall events, 1.21, 1.23 and 2.45 inches, may have caused leaching of N in the Svea well drained soils.

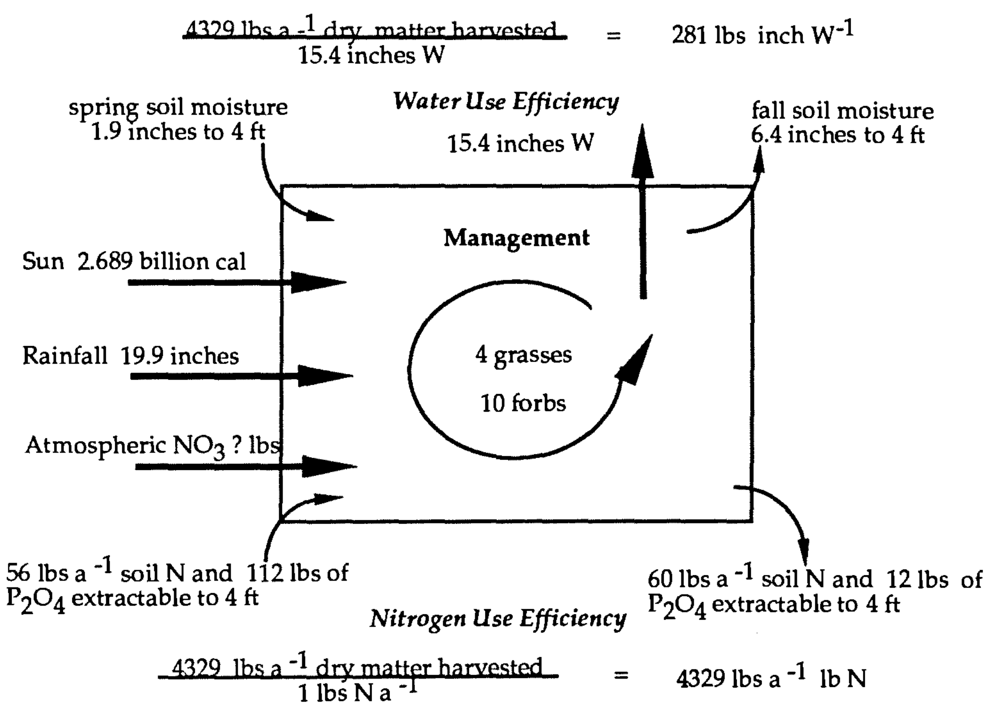


Figure 2.17. Gross inputs, outputs, and efficiencies from the central prairie site during the summer of 1991.

CENTRAL CONVENTIONAL SITE
Mixed grass prairie ecosystem

Geologic and Social History

The central conventional site, located in the west portion of Foster County, was geologically part of the glacial plains region. As the Wisconsin Glacier thinned, it became increasingly affected by the topographic highs over which it flowed and eventually became two distinct lobes--the James and Des Moines lobes (Bluemle, 1965).

The James lobe formed the topography of the central conventional site during the Grace City phase of glaciation. The glacier lacked the force to shear Sully's Hill but flowed on both sides of it leaving a band of stagnant ice on and to the south of the hill. The debris covered stagnant ice, formed a meltwater channel to the southeast, left many circular depressions averaging a few hundred feet wide to become Foster County's sloughs, and deposited glacial drift averaging 150 ft in thickness (Bluemle, 1965).

Bedrock was Cretaceous Pierre Shale and forms the eastern flank of the Williston Basin (Bluemle 1965). Although there are no oil wells in Foster County there were considerable sales of part interest in mineral rights during the 1950's and many test wells were drilled (Zink 1983).

The present owner's great grandmother immigrated from one of the islands that comprised the west country of Norway. This area is where the glaciated mountain canyons extend into the sea creating many islands and fjords which wind inland. Tiny fruit farms cling to the mountain sides in this region (Malmstrom et. al. 1955).

Great grandmother came to Minnesota with her parents and two brothers. One of her relatives (an uncle or cousin) was located in Foster County as a worker on the Great Northern Railroad. He stayed on to file a homestead claim, the first in the township, and encouraged this great grandmother to join him. She exercised her rights of preemption and bought a quarter of land adjoining her kinsman's for $1.50 per acre.

She also staked a claim two miles south where she had to reside and begin improvements in the way of permanent habitation within 6 months. Under the terms of the Homestead Act, she had to dwell there for 5 years before gaining title to the land. She was 25 years old at this time (Zink 1983). Melora Espy in *Pioneer Women* described the courage of these women in this way "To forsake culture, plenty, prosperity and peace, for crude living, poverty, adversity and war requires a poise of soul few possess" (Stratton 1981).

Grandmother's family did not occupy the central comventional site until the mid 1950's. These acres were originally part of the US government grant of 25,600 acres of Dakota Territory to the railroads. A local builder bought a half section for speculation and an emigrant from Kentucky was the tennant farmer until 1947 when he purchased the acres in an estate settlement. Nine years later he sold it to grandmother's family, the father of the present owner.

The central conventional site was located in the same township of Foster County as NDSU's Carrington Research Extension Center where this study of sustainable agriculture originated. Foster County has a history of providing training opportunities for its farmers. In 1912 the county sponsored the Farm Institute with speakers from the North Dakota Agricultural College (now North Dalota State University in Fargo). The local bankers sponsored a Holstein project in 1921 and a winter short course in 1952. In 1959 the Carrington Irrigation Station (now Carrington Research Extension Center) was formed as a branch station of NDSU for the purpose of agricultural research, seed increase, and education. The farm family from the central conventional site have been involved with the research and educational programs of the research station and their farming practices reflect this historical affiliation.

Native vegetation present in the glacial till grows in a transition zone between the tall grasses of the lake bottom lands and the short grasses of the western steppe (Bluemle 1965). The sampling regime for this study consisted of an in-depth evaluation of a level, one acre portion of a 158 acre field. The closest approximation to the index soil (Svea) was Emrick (Table 2.21, soil physical characteristics). It is a coarse loam as compared to the fine loam of Svea.

Soil Physical and Nutrient Characteristics

Measurements of the soil physical characteristics, bulk density, wet aggregate strength and dry aggregate size were taken from the central conventional site in 1990 and 1991 (Table 2.21). Surface soil samples from mid-July of 1990 and 1991 were separated for aggregate size distribution. Figure 2.21 shows the effect on soil aggregation by the different crops (wheat in 1990 and sunflower in 1991) present at the time of sampling. In 1990, 19 % of the soil particles were in the size category of less than 0.25mm while the soil supporting the sunflower crop had 24 % less than 0.25mm.

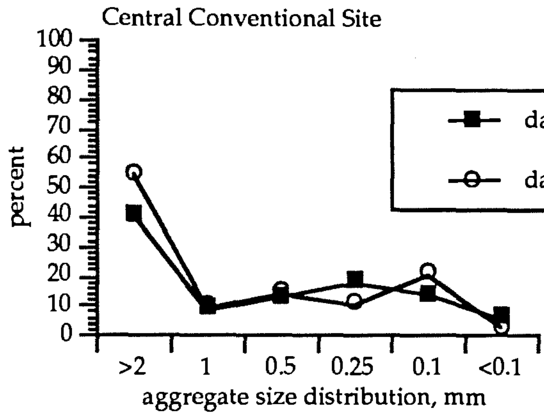


Figure 2.21. Soil aggregate size distribution for 1990 wheat acreage and 1991 sunflower acreage. The increase in particles below 0.1 mm size was a reflection of row-crop management.

Water stable aggregates of the central conventional site differed by year and by crop (Table 2.21). The aggregates from the 1990 wheat acreage were 70 percent water stable; the aggregates from the 1991 sunflower were 97 percent water stable. These numbers reflect a change in fall tillage practices. Prior to the spring of 1990 sunflower fields had been disked and small grains had been plowed followed by field cultivation; the changed management observed in this study was no tillage following the sunflower and small grains harrowed and chisel-plowed with 3-inch twisted spikes.

In this conventional farm agroecosystem, nitrogen entered the soil through atmoshperic precipitation, decomposition of organic matter, and application of industrial fertilizer. The farmer of the central conventional site subscribed to a soil testing service which conducted tests during the autumn for the past several years.

Based on the service's measurement, recommendations for the crop of interest, and the farmer's experience, 82 lbsa^{-1}. of anhydrous ammonium was applied in the autumn of 1989 and 80 lbs a^{-1}. of 18-46-0 were applied at seeding. In the autumn of 1990, 56lbs. a^{-1} of anhydrous ammonium was applied in preparation for the sunflower crop of 1991. Spring and autumn soil tests conducted in 1990 and 1991 showed a level of free nitrate and ammonium to the 48-inch soil depth (Table 2.21).

Table 2.21. Summary table of soil physical and chemical characteristics for the central conventional site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	29.06	34.76	14.66	9.64	11.79
fall	2.97	3.61	4.46	4.94	6.73
'91 spring	5.48	8.42	4.78	3.24	3.40
fall	1.82	3.80	1.55	1.40	2.80
Ammonium mg kg^{-1}					
'90 spring	4.44	12.01	3.53	3.09	2.22
fall	1.68	1.94	2.99	2.84	2.84
'91 spring	4.32	7.32	2.65	1.84	1.48
fall	1.44	2.61	2.74	2.21	1.07
Phosphorus mg kg^{-1}					
'90 spring	14.5	15.0			
fall	17.5	6.0			
'91 spring	16.0	5.5			
fall	13.0	5.5			

Soil Physical Characteristics

Horizon Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A_p 0–9	clay loam.	weak SBK part to gran.	neutral	common	
B_{w1} 10-16	clay loam.	weak SBK	neutral	common	
B_{w2} 17-21	clay loam.	weak SBK	neutral	few	fine yl. mtles.
B_k 22-29	clay loam	weak SBK	violent	few	fine c. yl. mtles.
C 30-48	clay loam	massive	strong	none	few md.br.mtles.

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
1.12g cm^3	7.4	2.81%	5215	0.99%	52
1.13g cm^3	7.1	3.37%	880	1.28%	11

Aggregate Stability
70%
97%

Abbreviations defined:
*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

Organic matter increased from 2.81% in 1990 to 3.37% in 1991 (Table 2.21). Janzen (1987) states that tillage hastens the mineralization of labile organic matter and promotes the conversion of labile N materials to stable humified organic materials. Fall tillage practices on the central conventional site changed from plowing and disking to harrow and chisel plowing with no tillage following the sunflower harvest.

The nitrogen mineralization and immobilization transformation cycle was affected by factors such as the residual nitrogen remaining from the previous year, the amount, source, timing and method of application of the current year's infusion of nitrogen, the current year's response to climatic factors such as precipitation and temperature and the way in which all of the factors affect the biological system.

In an attempt to quantify the effects of these dynamics on soil fauna (bacteria, mites, and springtails) soil cores were extracted to a depth of 15 cm on eight separate days from June to September, 1990 (Figure 2.22) and April to November, 1990. The microbe populations hit a peak on day of year 170 (June 19th) of 1990 and subsequently declined to a low level for the balance of the study. Springtail populations peaked on day of year 210 (July 29) for both years. There was more variation of springtail poulations under the sunflower production; the crop was cultivated on day of year 178 (June 26) and 179 (June 29). Both springtail and mite populations increased after that date. The mite population was relatively stable for the 1990 wheat crop and the variation in 1991 may have been due to disturbance by cultivation as mentioned previously.

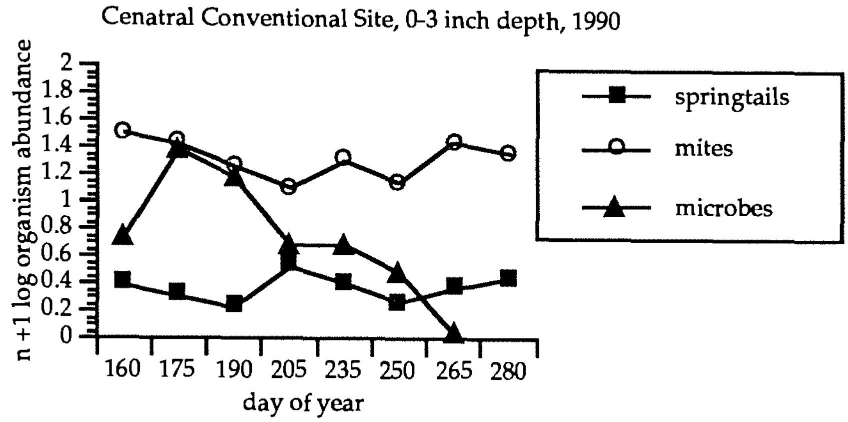


Figure 2.22. Soil fauna population measurements at one soil depth and eight sample dates for 1990. Wheat crop harvested day of year 228 (August 16) harrowed on day of year 236 (August 24), and field cultivated on day of year 250 (September 7)..Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg $^{-1}$ ammonium for g dw soil.

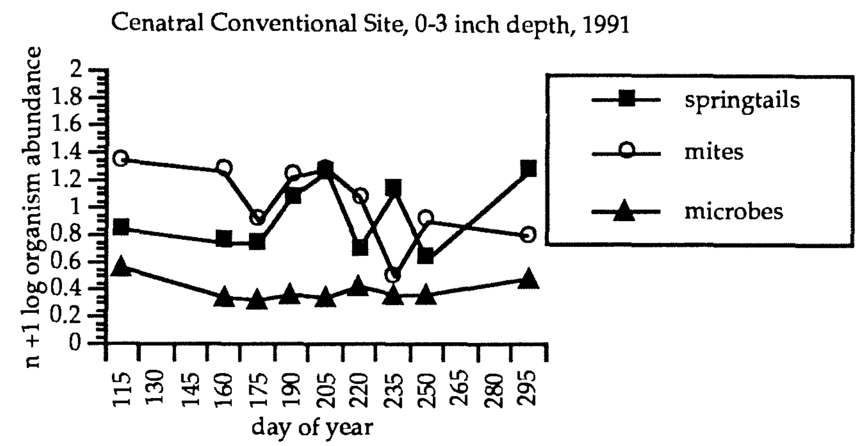


Figure 2.23. Soil fauna population measurements at one soil depth and nine sample dates for 1991. The crop was sunflower; they were cultivated day of year 178 June 27). Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg $^{-1}$ ammonium for 1g dw soil.

In addition to microarthropods other arthropods were quantified to obtain a better understanding of the biodiversity on this site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to argiculture is not well documented.

Pitfall traps were collected on seven successive sample dates for 1990 and five sample dates in 1991 (Figure 2.24). The predominant arthropods collected in 1990 were as follows: spiders (8 families), beetles (6 families), flies (8 families), and bees, true bugs, hoppers, and thrips (each 2 families). There was much less diversity observed in the 1991 collections. The daddy longlegs spider *(Phalongida)*, ground beetle *Carabidae)*, buffalo gnat *(Simuliidae)*, and burrowing bee *(Halicitdae)* comprised most of the pitfall trap organisms quantified in 1990 and 1991 collections.

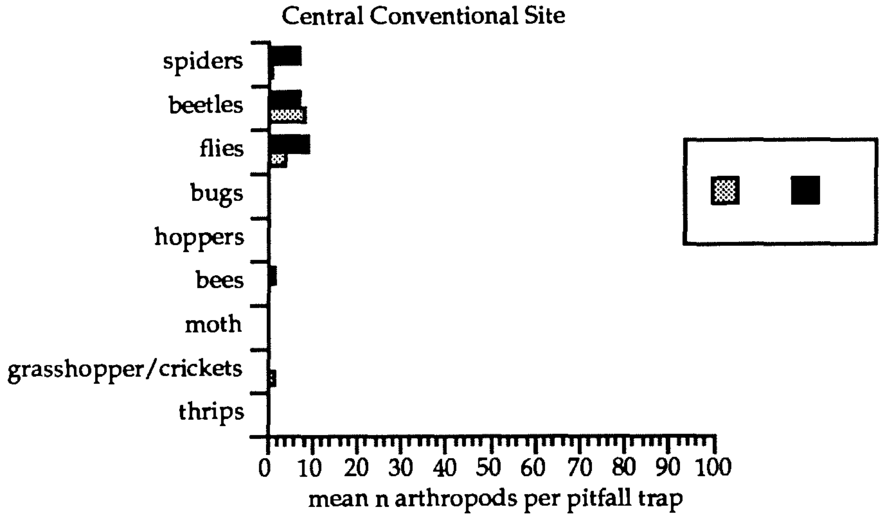


Figure 2.24. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 5 sample dates in 1991. Numbers are the mean arthropods per trap for the sample period. Sample size =12 oz cup set at soil level for 4 consecuative days.

The Mragalef index is an index of diversity. In this study it was applied to insect families and the higher number indicates the greater diversity. The chart above indicates that there were not many insects collected from this site but those collected indicated a fair amount of diversity as shown in table 2.22 below.

Table 2.22. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores.

Margalef Index of Pitfall Trap Insects

Central conventional	**Predators**						**Herbivores**					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	3.36	1.16	2.98	2.84	3.60	4.00	0.71	0.58	0.40	0	0.56	1.88
1991	2.32	3.17	0	3.19	2.44	1.36	1.06	0.98	0	2.11	1.06	0.64
mean	2.84	2.17	1.49	3.02	3.02	2.68	0.89	0.78	.20	1.06	0.81	1.26

Plant Species Present

The vegetation present (Table 2.23) consisted primarily of grasses in 1990 and forbs in 1991. The typical crop rotation for this site was hard red spring wheat *(Triticum aestivum 'Amidon')* and sunflower *(Helianthus annuus 'Cargill-SF 100').* In 1990 no weeds were observed until mid-July when kochia *(Kochia scoparia)*, green foxtail *(Setaria virdis)*, and wild oats *(Avena fatua)* were observed. Early infestations of green foxtail, red-root pigweed *(Amaranthus retroflexus)*, and wild mustard *(Brassica kaber)* in 1991 increased until the crop covered the ground. There were no observations of weeds the first week of August.

Table 1.23. Plants present in the central conventional agroecosystem.

Central Conventional System Species

Triticum vulgare 'Amidon'	*Avena fatua*	*Amaranthus retroflexus*	*Brassica kaber*
Helianthus annuus 'Cargill-SF 100'		*Kochia scoparia*	*Setaria virdis*

Soil Moisture

The amount of plant available soil moisture (Table 2.24) was an important factor in determining plant growth. Soil moisture was determined at this site by gravimetric sampling to a depth of 48

inches during spring and autumn of 1990 and 1991. Precipitation estimates recorded at the nearest weather station during this period totaled 13.59 inches for 1990 and 21.94 inches for 1991.

Table 2.24. Total soil moisture at 0-48 inches sampling depth for spring and fall 1990 and 1991.

	Soil Moisture							
	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.68	0.64	1.28	1.81	3.96	8.37	13.59	16.0
fall	0.50	0.53	1.02	1.15	2.75	5.95		
'91 spring	0.53	0.89	1.14	1.28	3.14	6.98	21.94	21.2
fall	1.43	0.78	1.18	1.72	2.62	7.73		

Management

Management practices on this site have consisted of a wheat/sunflower rotation. Wheat fields were prepared during the autumn of 1989 by disking and applying anhydrous ammonia at the rate of 65 lbs. a^{-1}. Amidon wheat was treated with Granol Plus TM (maneb + thlabendazole) and seeded, April 21, at the rate of 100 lbs.a^{-1}, with an air seeder. Granular fertilizer (80 lbs. a^{-1} of 18-46-0) was applied at seeding. One week after emergence, the crop was sprayed for broadleaf weeds with MCPA at the rate of 3/4 pt. a^{-1}. The autumn field operations following the wheat crop included one harrowing followed by chisel plowing with 3 inch twisted spikes and anhydrous application at the rate of 56 lbs. a^{-1}.

During spring of 1991, Trilin TM granules were applied (10 lbs. a ^{1}.) and worked in with a chisel plow to control grasses. The oil sunflower were treated with metalaxyl (Apron TM) to control downy mildew (*Plasmopara halstedii*). The crop was seeded at the rate of 22100 seeds a^{-1} with a John Deer Maxemerge finger planter at the end of May. The field was then row cultivated one month later. There was 5% hail damage to the crop and 13 acres were flooded. There was no fall tillage applied to this field.

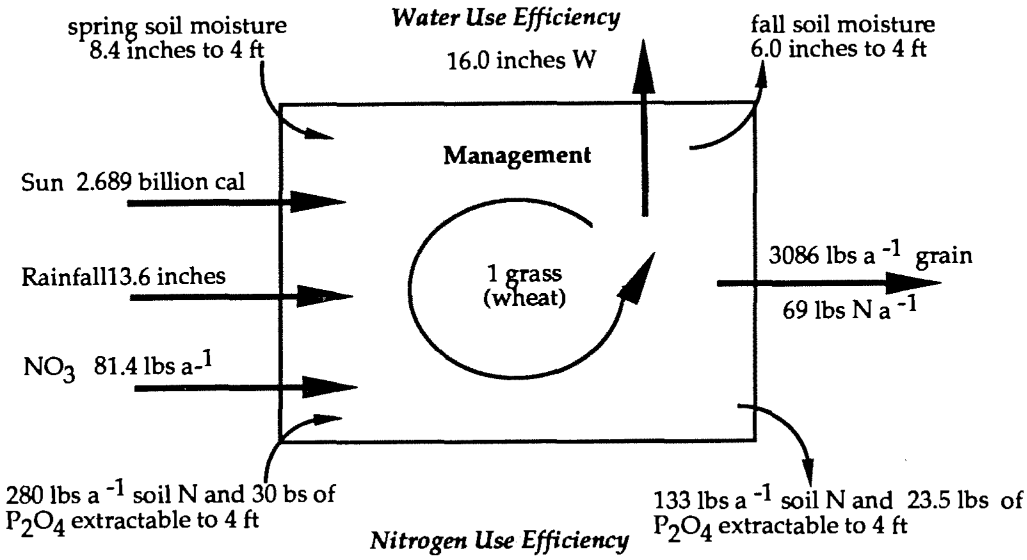
Production and Resource Use Efficiency

The site was harvested by straight combining the wheat crop in mid August. The net primary production (NPP) was 11,545 lbs. a^{-1} with 3086 lbs. a^{-1} marketable as grain (farmer field estimate 50.6 bu a^{-1}). Nitrogen removed with the crop was 69 lbs. a^{-1}.

For sunflower, straight combined in mid October, the NPP was 6831 lbs. a^{-1} with 1627 lbs. a^{-1} (farmer field estimate) as marketable grain (1/3 of crop was contracted).

Using pre-season and post-season soil samples taken to a 48-inch depth, total gravimetric water, nitrate, and ammonium content were determined mathematically. Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen plus nitrogen inputs, gross nitrogen and water use efficiencies were calculated (Figures 2.25and 2.26).

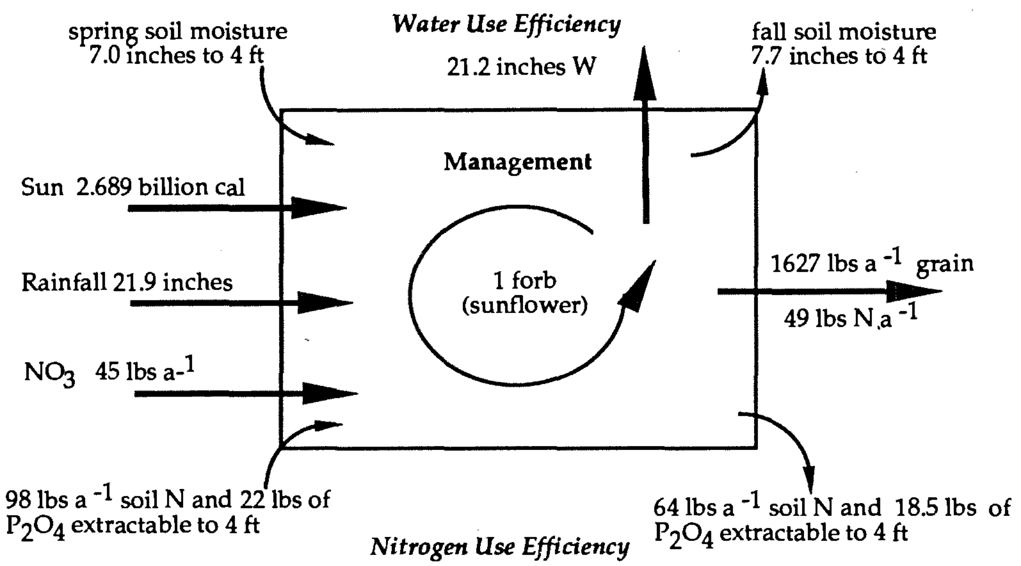
$$\frac{11{,}545 \text{ lbs a}^{-1} \text{ dry matter harvested}}{16.0 \text{ inches W}} = 722 \text{ lbs inch W}^{-1}$$



$$\frac{11{,}790 \text{ lbs a}^{-1} \text{ dry matter harvested}}{147 \text{ lbs N a}^{-1}} = 80 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 2.25. Gross inputs, outputs, and efficiencies from the central conventional site 1990. Fertilizer inputs applied before study soil test and are reflected in the 280 lbs a^{-1} N and 30 lbs a^{-1}P values. Fall 133 lb a^{-1} N sample includes the 45 lbs a^{-1} N credited to the 1991 crop.

$$\frac{6{,}831 \text{lbs a}^{-1} \text{ dry matter harvested}}{21.2 \text{ inches W}} = 322 \text{ lbs inch W}^{-1}$$



$$\frac{6{,}831 \text{ lbs a}^{-1} \text{ dry matter harvested}}{34 \text{ lbs N a}^{-1}} = 201 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 2.26. Gross inputs, outputs, and efficiencies from the central conventional site 1991. Fertilizer inputs applied before study soil tests and are reflected in the 98 lbs N.

CENTRAL NO-TILL SITE

Mixed grass prairie ecosystem

Geologic and Social History

As the Wisconsin glacier passed over North Dakota, more than 12,000 years ago, it sculpted the landscape and left behind 500 feet of glacial till. This glacial sediment comprised a portion of the Coleharbor group and was deposited on a layer of Cretaceous Pierre Shale bedrock in a region referred to as the glacial plains.

The central no-till site was located in Towner County within the glacial plains region. The Pierre Shale bedrock, which forms the eastern flank of the Williston Basin, has been sampled and was not shown to contain any petroleum deposits. The lower most depths of the glacial till consisted of a 300 foot layer of sand and gravel, part of the Spiritwood aquifer system. The low rounded hills comprising the topography of the surface was formed by the lateral movement of the supra-glacial sediment as the glacier subsided and the underlying ice melted. Steep sided gullies were cut by the melt water, sloughs were formed, and eskers (ice contact ridges of gravel with a thin veneer of till) remained (Bluemle, 1984 and 1988).

Early records of human settlement date back to the 1700's. Chippewa bands of Native Americans emigrated to the glacial plains, enticed by the abundant food resources which included the plains bison. In 1863 Chippewa bands claimed about 5 million acres north and west of Devils Lake. By 1884 the President of the US confined them to two townships in Rolette County. Formal cession did not take place for another 10 years when the US government agreed to pay $1,000,000 in goods such as horses, cattle, housing etc. at the rate of $50,000 per year. Until the 1920's these Native Americans traveled the coulees digging roots and other herbs used for cooking and medicine and traded with the settlers (Robinson 1966, Bisbee 1988).

The present owner (son of the superintendent of schools) married the farmer's daughter who's grandfather homesteaded the land. At age 18 grandfather immigrated from Germany to Chicago to stay with an uncle. After a few years, he set off for Hillsboro, ND, to work on a farm (Towner County 1989). Some settlers from the Hillsboro area would go to Towner County to break as much sod as possible during the summer and then return to more populated areas for the winter.

It was logical that grandfather, after being in America for eight years, would file claim on the "new" lands in Towner county. The county was the crossroads of two railroads, the Soo line and a branch line of the Great Northern; their influence on the county was considerable. Initially they recruited two major settlements of homesteaders, the Missouri Colony of 40 men friends and the German Baptist Brethren Colony. By 1916 there were 638 cars of grain and 140 cars of livestock shipped annually. Some farmers would winter vacation by riding the freight train to Minneapolis to market their cattle. In 1890 the railroad initiated the Farmers Alliance to help farmers and farm interests and also to induce more settlers to come to the county (Bisbee 1988, Cando 1984).

Towner County has a rich tradition of educational support for the farmers. As early as 1909 the county sponsored the longest session of the Farm Institute lasting 3 days. They supported a county agent as early as 1914 and fostered agricultural contests to encourage crop and livestock improvement (Bisbee 1988, Cando 1984).

With agricultural technical assistance in place, it wasn't surprising that the current farm owner of the central no-till site, an NDSU economics major with a love for the outdoors, would jump at the chance to be a farmer when the land of his wife's heritage was offered for sale. Not being experienced in the ways of conventional agriculture, this farmer was impressed by the conservation claims of Manitoba-North Dakota Zero Tillage Farmers Association and was open to trying no-till farming methods. He was quoted after 10 years of no-till system management, "The soil loss from my farm is virtually zero." This quote was verified when the research staff for this study observed his lands immediately after a once in 50 years rainfall event. This farmer

continues his training through production oriented farm organizations and extension service training sessions. His wife was an integral part of the production operation. In addition to grains and hay, the family raise sheep on this farm.

The sampling regime for the study of this farm consisted of an in-depth evaluation of a level, one acre portion of a 62 acre field. The index soil was Seva (Table 2.31, soil physical characteristics). Once covered with native vegetation of mixed grasses in transition between tall grass species and western short grasses (Bluemle 1965), it was used for the production of small grain, buckwheat, flax, sunflowers, soybeans, alfalfa and pasture. Note that the A horizon extends down to 18 inches (Table 2.31); this was a reflection of the effects of no-till practices.

Soil Physical and Nutrient Characteristics

Measurements of the soil physical characteristics such as bulk density, wet aggregate strength and dry aggregate size were taken from the central alternative site in 1990 and 1991 (Table 2.31). Though different crops were raised (wheat / sunflower) dry soil aggregation was the same for both 1990 and 1991 (Figure 2.31). Fine aggregates of less than 0.25mm were 6 percent of the total.

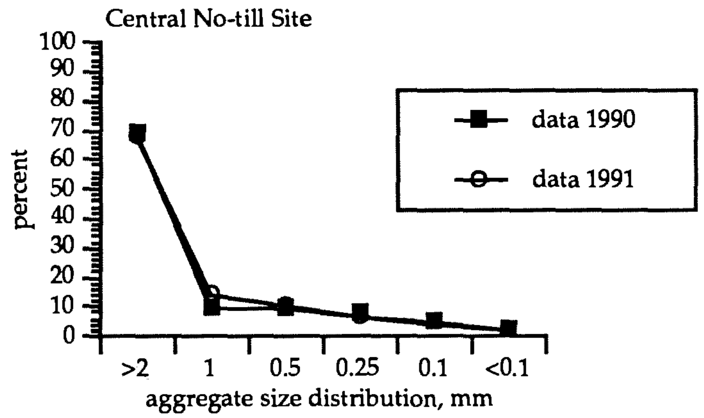


Figure 2.31. Soil aggregate size distribution for 1990 wheat acreage and 1991 sunflower acreage.

In this no-till farm agroecosystem, nitrogen entered the soil through atmospheric precipitation, decomposition of organic matter, application of industrial fertilizer and small amounts of manure as produced by the sheep. The farmer of the central no-till site subscribed to a soil testing service which conducted tests during the autumn for the past several years.

Based on the service's measurement, recommendations for the crop of interest, and the farmer's experience, 36 lbs a^{-1}. of 18-46-0 were side banded at seeding for the 1990 wheat crop. In 1991, 100 lbs a^{-1}. of 18-46-0 were side-banded at seeding to 15 acres of the 62 acre field. Soil tests conducted for this study in the spring and autumn of 1990 and 1991 showed a level of free nitrate and ammonium to the 48 inch soil depth (Table 2.31). The spring soil tests were taken before the application of industrial fertilizer.

Table 2.31. Summary table of soil physical and chemical characteristics for the central no-till site.

Nutrients

Nitrate $mg\ kg^{-1}$	0-3	3-6	6-12	12-24	24-48
'90 spring	8.41	15.71	11.86	6.01	6.01
fall	13.40	6.51	5.77	2.06	3.05
'91 spring	5.60	6.71	4.55	2.41	1.99
fall	2.94	2.02	1.47	0.66	0.23
Ammonium $mg\ kg^{-1}$					
'90 spring	2.07	2.31	3.16	2.41	1.97
fall	1.39	1.31	0.76	0.71	0
'91 spring	4.18	3.38	2.96	3.33	2.25
fall	3.82	3.38	3.68	1.71	2.99
Phosphorus $mg\ kg^{-1}$					
'90 spring	22.0.	7.0			
fall	22.5	7.0			
'91 spring	22.5	8.0			
fall	23.0	9.0			

Soil Physical Characteristics

Horizon Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A_p 0--10	loam.	weak SBK	neutral	common	
A 11-18	loam.	weak SBK	neutral	common	light color
B_w 19-25	sandy loam	weak SBK	neutral	few	
B_k 26-39	loam	weak SBK	violent	few	fine c. yl. mtles.
C 40-48	loam	massive	strong	none	fine c. yl. mtles

**Bulk Density	pH	Organic matter	Light F. $mg\ kg^{-1}$	TKN	N $mg\ kg^{-1}$
0.81g cm^3	6.8	5.23%	8300	1.57%	130
0.968g cm^3	7.2	5.43%	1955	0.85%	13

Aggregate Stability
94%
95%

Abbreviations defined:
*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

The very fine particle lightfraction component of total soil organic matter was considerably different for the two years of the test (Table 2.31). The spring of 1990, when these tests were taken, was preceded by two years of drought. Verhoef and Brussard (1990) observed that springtails and mites continue to breakdown organic matter in times of drought. Mineral N accumulated would become available for plants upon rewetting of the soil.

In addition to the application of industrial N, the nitrogen mineralization and immobilization transformation cycle was affected by factors such as the residual N remaining from the previous year (Table 2.31). The current year's response to climatic factors such as precipitation and temperature and the way in which all of these factors affect the biological system. In an attempt to quantify the effects of these dynamics on soil fauna (bacteria, mites, and springtails) soil cores were extracted to a depth of 15 cm on eight separate days from June to September, 1990 (Figure 2.32).

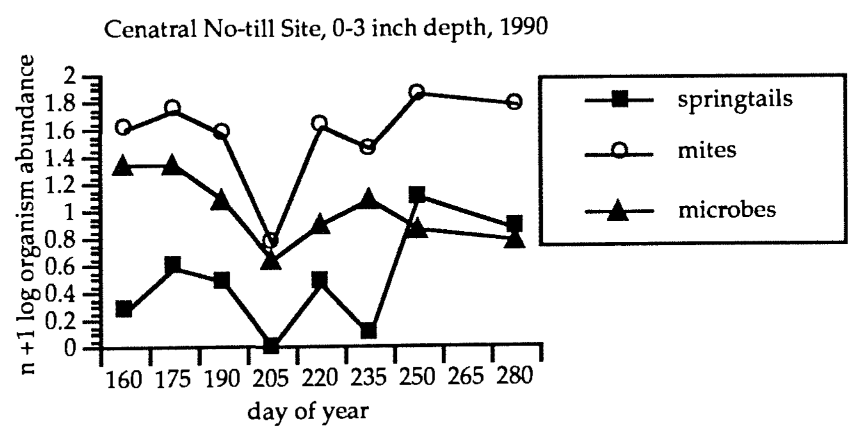


Figure 2.32. Soil fauna population measurements at one soil depth and eight sample dates for 1990. The crop grown on this site was wheat. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1g dw soil.

Microbe populations were highest in the spring and decline to their lowest point day of year 210 (July 29) which was also the time of lowest population levels for all three organisms. Average soil temperatures for the time interval prior to day of year 190 (July 9) were 63°F. Prior to day of year 210 there were 61°F and prior to day of year 230 (August 18) they were 62°F. These soil

temperatures were recorded at the same latitude on bare ground 50 miles to the east of the central no-till site. The mitigating effects of the trash mulch of the no-till system was undetermined.

Rainfall for the time interval prior to day of year 210 was 1.31 inches in 5 rainfall events. Prior to day of year 190 there was 1.30 inches of rainfall in 5 precipitation events and prior to day of year 230 there was no rainfall. For the balance of the sampling period the microbes and mites were at higher population levels. The springtails reached their highest population level on day of year 270 (September 27th)

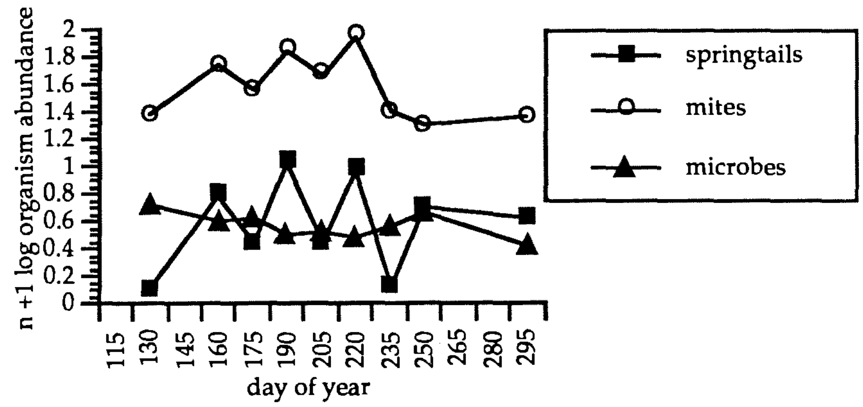


Figure 2.33. Soil fauna population measurements at one soil depth and nine sample dates for 1991. The acreage was harrowed 10 days prior to the first sampling date. The crop was sunflower. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg^{-1} ammonium for 1g dw soil.

The microbe activity was static for the observation period on this site in 1990. This population level was similar to other sunflower sites observed in this study. The population peaks for the mite population patterns correspond with the springtail patterns. The mite populations peaked at day of year 220 (August 8); the springtail populations were similar for days of year 190 (July 9) and 220.

In addition to microarthropods other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented.

Pitfall traps were collected on 7 successive sample dates for 1990 and 6 sample dates in 1991 (Figure 2.34). The predominant arthropods collected were as follows: spiders (4 families), beetles (5 families), flies (8 families), bees (5 families) and crickets (1 family plus some grasshoppers). The daddy long legs spider *(Phalangid)*, ground beetles *(Carabidae)* the bee fly*(Bombyliid)*, buffalo gnat *(Simuliidae)* burrowing bee *(Halicitdae)* and crickets *(Gryllidae)* comprised the most of the pit fall trap organisms quantified in 1990 and 1991.

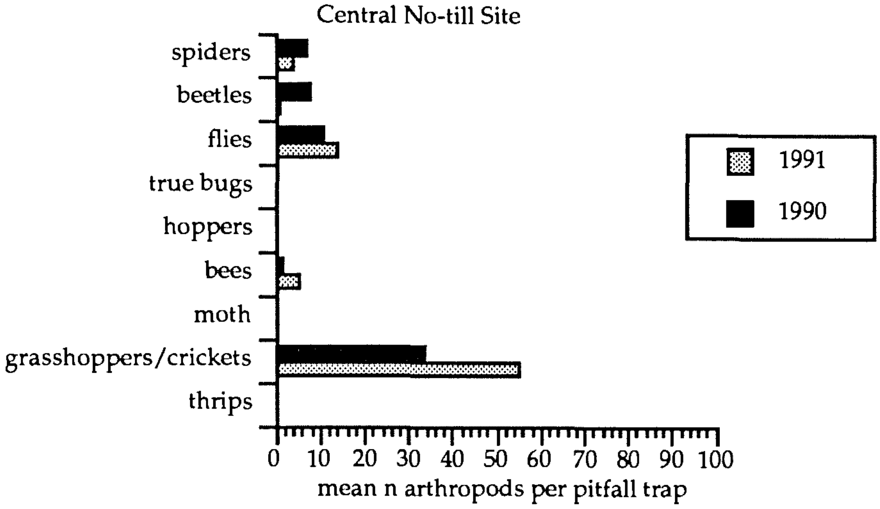


Figure 2.34. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 6 sample dates in 1991. Numbers are the mean arthropods for sample period. Sample size =12 oz cup set at soil level for 4 consecuative days.

The Margalef index is an index of diversity (Table 2.32). In this study it was used to indicate the diversity of insect families. The higher the number the greater the diversity.

Table 2.32. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores from the central no-till site.

Margalef Index of Pitfall Trap Insects

Central no-till	**Predators**						**Herbivores**					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	3.27	4.72	3.18	2.85	3.70	1.80	0.37	0.32	0.07	0.32	0.14	0
1991	5.50	2.78	2.52	2.84	2.62	3.16	0	1.02	1.02	0.28	0.40	0.16
mean	4.39	3.75	2.85	2.85	3.16	2.48	0.19	0.67	0.55	0.29	0.27	0.08

Plant Species Present

The vegetation present (Table 2.33) consisted primarily of grasses in 1990 and forbs in 1991. The typical crop rotation for this site was wheat *(Triticum aestivum 'Nordic')* and sunflower *(Helianthus annuus 'Sigco 954')*.. Green foxtail *(Setaria virdis)* was counted on three observation dates (6/25, 7/13, and 7/25 of 1990) with densities of 10.8, 25.4 and 6.2 plants per square foot. Those observed on 7/27 were newly emerged. Wild buckwheat *(Polygonum convolvulus)* was observed on sample dates 6/28 and 7/13 with a density of 1 and 1.6 sq. ft $^{-1}$. Volunteer clover *(Trifolium pratense)* was observed on the 7/13 sample date at the rate of 1.6 plants sq. ft $^{-1}$. Another grass observed in 1990 in small numbers was wild oats *(Avena fatua)*. Green foxtail was observed in greater densities (6/13 - 2.8, 6/26 - 2.6, and 7/10 - 3.8) until the crop reached a height of 50 inches and the canopy shaded them (7/24). Light infestations of wild oats and Russian thistle *(Salsola iberica)* were also observed in 1991.

Table 2.33. Plants present in the central no-till agroecosystem.

Central No-till System Species

Triticum aestivum 'Nordic'	*Avena fatua*	*Polygonum convolvulus*	*Setaria virdis*
Helianthus annuus 'Sigco 954'	*Salsola iberica*	*Trifolium pratense*	

Soil Moisture

Observations for soil moisture followed 2 years of drought. Available soil water at the 0-48 inch depth for November 6, 1989 in Towner County was estimated to be 1-2 inches (Extension SF 760, 1990). Winter and spring recharge (4 inches of snow 4/28) for the central no-till site yielded total soil moisture of 7.35 inches for this study's tests on May 3, of 1990 (Table 2.34). On August 5th, 1991 this site received a rainfall event totaling 4.4 inches in less than 12 hours. According to USDA-SCS estimates, there is a 2 percent chance (50 year event) for this area to receive 4.2 - 4.3 inches of rainfall in 24 hours (SCS 1974).

Table 2.34. Total soil moisture at 0-48 inches sampling depth for spring and autumn 1990 and 1991.

	Soil Moisture							
	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.57	0.98	1.60	1.23	2.97	7.35	8.50	9.24
fall	0.61	0.62	0.80	1.62	2.96	6.61		
'91 spring	0.97	0.88	0.97	1.06	2.35	6.23	22.63	17.00
fall	0.71	0.91	1.57	3.30	5.35	11.84		

Management

The objective of no-till farm management is to make as few trips across the field as possible, disturb the stubble mulch as little as possible to control wind and water erosion and maintain or increase production in the process (Proceedings, Conservation Tillage 1990). The management practices on this site have consisted of a wheat/sunflower rotation. The farmer subscribes to a crop consulting service to advise on weed, insect and disease problems. The drought of the previous two years has enabled this farmer to farm the potholes. The following report of small acreages sprayed was a reflection of treatment for those potholes.

In 1990 five acres of the 62 acre site was treated with a preplant herbicide application of glyphosate (Round Up RT. TM 1.5 pts a^{-1}) and dicamba (Banvel TM 1 oz a^{-1}) to control emerged grass and broadleaf weeds especially wild buckwheat. Nordic wheat treated with carboxin (Vitivax TM) for seed borne diseases was planted on May 9th at the rate of 1.15 bu a^{-1} by means of a Haybuster drill pulled with a 1466 International tractor. Industrial fertilizer (18-46-0) was side banded at the rate of 36 lbs a^{-1}.

Ten days after seeding, 45.6 acres were sprayed with glyphosate (Round Up RT. TM 8 oz a^{-1}), 2,4-D ester (8 oz a^{-1}) and 0.2% Ammonia Sulfate (17 lbs a^{-1}). General observations of the stand seem to indicate some difficulty with seeding through the accumulated surface trash. Two weeks after seeding 42.6 acres were sprayed with metsulfuron (Ally TM 1 oz a^{-1}). Twenty days later 20 acres of the site were sprayed with imazamethabenz (Assert TM 12.8oz a^{-1}), tribenuron (ExpressTM 0.125oz a^{-1}), and 0.2% Ammonia Sulfate. Twenty six days after seeding 3.3 acres were sprayed with tribenuron (0.167oz a^{-1}), 2,4-D ester (10.7oz a^{-1}), and 0.2%Ammonia Sulfate. All of these treatments were intended for the control of broadleaf weeds especially wild buckwheat.

For production year 1991, the acreage was harrowed in early April. At the end of April, 62.1 acres were sprayed with the herbicide pendimethalin (Prowl TM 3pts a^{-1}) to control grasses and some broadleaf species. Sigco 954 confection sunflower was solid seeded at the rate of 17,194 seeds a^{-1} the third week of May with a Haybuster drill. Fifteen acres had 18-46-0 industrial fertilizer side-banded at the rate of 100 lbs a^{-1}. Fifteen acres were treated with glyphosate (24oz a^{-1}) and 2 acres were treated with glyphosate at the rate of 32oz a^{-1} three days after seeding. All of the acreage (62.1 a) was treated with dimethoate (Cygon TM) to control sunflower beetle (*Zygogramma exclamationis*). Twenty two acres were sprayed with methyl parithion (0.5 lbs active ingredient a^{-1}) to control seed weevils.

Production and Resource Use Efficiency

The 1990 wheat was swathed the third week of August and combined the 1st of September. Net primary production was 6690 lbs a^{-1} with 1850 lbs a^{-1} marketable grain (farmer estimate 36.7 bu a^{-1}). Nitrogen removed with the crop was 35 lbs a^{-1}. The confection sunflower crop (1991) was harvested October 11th; NPP was 8266 lbs a^{-1} with an estimated seed yield of 2421 lbs a^{-1}. Nitrogen removed with the crop was 78.4 lbs a^{-1}.

Using preseason and post-season soil samples taken to a 48 inch depth, total gravimetric water, nitrate, and ammonium content were determined mathematically. Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen plus nitrogen inputs, gross nitrogen and water use efficiencies were calculated (Figures 2.35 and 2.36).

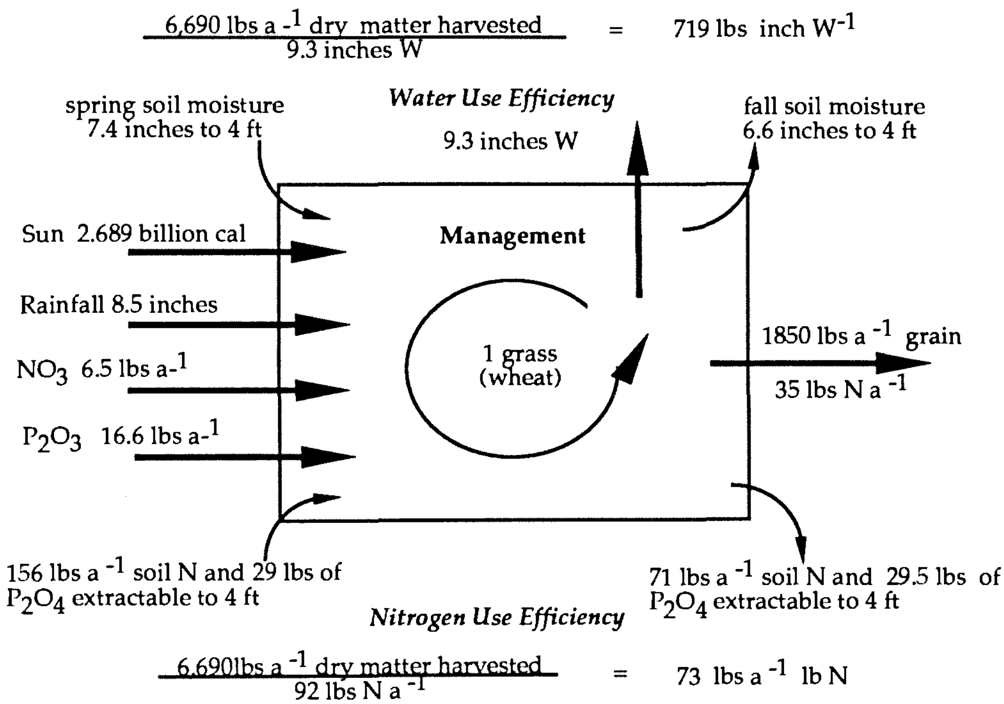
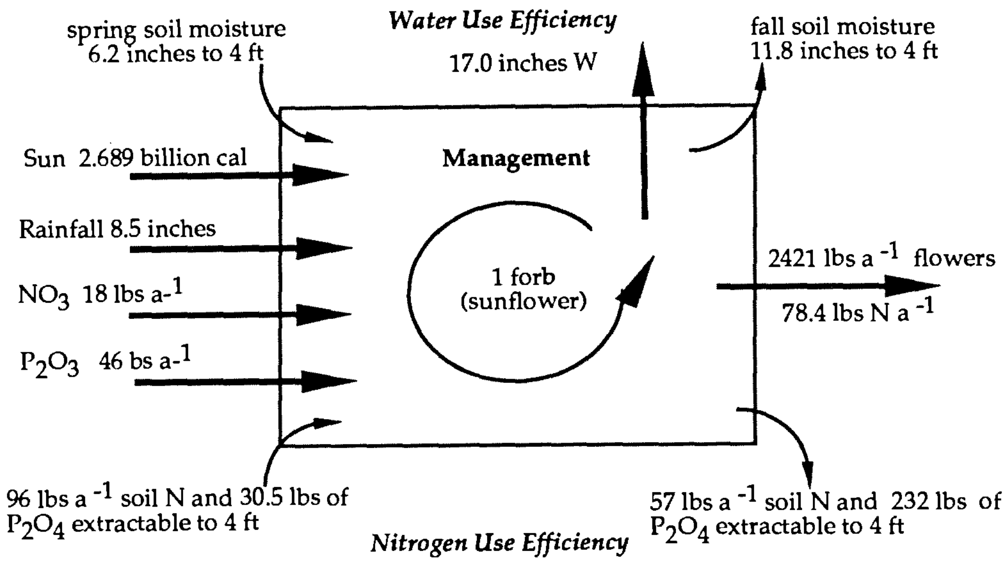


Figure 2.35. Gross inputs, outputs, and efficiencies from the central no-till site, 1990. Spring extractable N and P values represent tests taken prior to inputs.

$$\frac{\text{8,266lbs a}^{-1}\text{ dry matter harvested}}{\text{17.0 inches W}} = \text{486 lbs inch W}^{-1}$$



$$\frac{\text{8.266 lbs a}^{-1}\text{ dry matter harvested}}{\text{57 lbs N a}^{-1}} = \text{145 lbs a}^{-1}\text{ lb N}$$

Figure 2.36. Gross inputs, outputs, and efficiencies from the central no-till site, 1991. Spring extractable N and P values represent tests taken prior to inputs.

CENTRAL ORGANIC SITE
Mixedgrass prairie ecosystem

Geologic and Social History

The central organic site was located within the James River Basin which empties into the Gulf of Mexico. The Continental Divide separates the Gulf of Mexico and the Hudson Bay drainage areas and crosses the western part of Barnes County to the east of the central organic site. Within the bedrock lies the Spiritwood channel. Six miles wide and eroded deep into the bedrock it was part of a larger southeast trending preglacial drainage system.

As the Des Moines lobe of the Wisconsin glacier receded, it left behind 7 distinct drift units in Barnes County. Millarton was one of the oldest drifts comprising the drift prairie of central North Dakota. It formed the southwest corner of Barnes County by filling in the Spiritwood channel and placing a thin layer of drift over the bedrock. The topography was mostly flat and there was little integrated drainage. Most of the runoff collected into shallow undrained depressions or sloughs. Materials comprising the drift ranged from sand to clayey silt. The color was yellowish brown, moderate to very calcareous, and had moderate quantities of rock fragments. The 12,000 years since glaciation have turned the top 20 inches to dark gray and dark grayish brown neutral soils through weathering and native grass production (Kelly and Block 1967). Historical evidence indicates that the sod was not broken on this site until the early 1940's.

A Folsom arrow point found in this region indicates that indigenous peoples used this site as early as 8500 to 8000 BC. These Native Americans raised corn, squash and sunflower; lived in earthen lodge villages, and hunted the bison and other game animals. Euro-American settlement began affecting prehistoric people by the 1700's. Cheyenne were burned out of their last village in this area by the Dakota Sioux who were pressured by eastern frontier settlements (Brennan et.al. 1986).

A major plan for organizing land settlement by the US government was to grant the railroads lands which they could sell to raise capital. Under the direction of James B. Power, the Northern Pacific Railroad decided upon a "gigantic land disposal program" (Drache 1964). The program was marketed as a capital investment venture with the hope of attracting wealthy investors. Individuals with large bond holdings traded their bonds for large tracts of land, hired a farm manager and employed the cheap immigrant labor necessary to farm the fertile prairies of North Dakota. This management strategy resulted in a "factory approach" to farming and would eventually become known as the "Bonanza Farms." The Johnson Land and Cattle Company of Barnes County was one such enterprise and by 1910 it owned 36 sections in the southwest portion of the county.

The "main" farm consisted of three farms at a cross-roads of 4 section lines. The central organic site was formerly one of these farms. This bonanza farm at its peak was reputed to be the largest poultry plant west of New York State. It produced 40,000 chickens as fryers, had hens which laid 2000-3000 eggs per day, had a hotwater heated incubator which held 32,000 eggs, a dairy with 100 milking Holsteins plus replacement stock, and produced 12, 000 pigs annually. They reportedly had a flowing artesian well which in addition to supplying the requirements for the livestock was forced through a water works to generate electricity for the farm. There were 145 buildings on the farm including a dairy. Located at the end of a Northern Pacific branch-line, the train was used to transport direct marketed goods from Barnes County to Minneapolis (Brennan et. al. 1986).

Intended for high profit to the out of state investors, these farms were in fact high risk and low profit. Size did not make these farms less vulnerable to drought and depression than the homesteaders' land. The bonanza farms were disliked by the homesteaders and an anti corporation farming law was passed by the legislature in 1932 (Wilkins 1977).

By 1933 this farm was sold to the grandfather of the present owner. The livestock was gone, the buildings had been moved off, and the artesian well had stopped flowing. Grandfather and the

father of the present owner set the plow to virgin prairie enriched with 30 years of livestock manure. Because of the rough times of the 1930's grandfather let the title of the farm revert to the Federal Land Bank and his son bought it for himself and his bride in 1944. She was credited for having witched for the water that flows from a well to this day.

The newly plowed sod produced abundantly. The father of the present owner bypassed the chemical revolution because that "stuff" was too expensive, required extra machinery and he just didn't want that "stuff' on the soil. He felt it affected the health of the soil. No one called it organic farming at that time and there were no premiums for the crop. This father and the present owner, his son, continue to perfect this system of farming for their lands and have shown the way to others.

The sampling regime for the study of the central organic site consisted of an in-depth evaluation of a level, one acre portion of a 19.1 acre field. Typically the fields on this farm were portioned into 20 rod strips. The index soil was Seva (Table 2.41, soil physical characteristics), Once covered with native vegetation of mixed grasses in transition between tall grass species and western short grasses (Bluemle 1965), this farm was presently used for the production of wheat, durum, oats, barley, clover, buckwheat, millet, flax, corn, soybeans and confection sunflowers. The choice of the crop depends upon the condition of the land, the anticipated weather, and the potential market for that season. These grains are conditioned before they leave the farm for market. A plow-down legume was used every third year of the rotation.

Soil Physical and Nutrient Characteristics

Measurements of the soil physical characteristics such as bulk density, wet aggregate strength and dry aggregate size were taken from the central organic site in 1990 and 1991 (Table 2.41). Water stable aggregates were 6 percent less for the clover/fallow acreage in 1990 than the soybean acreage in 1991 (Table 2.41). Fine dry aggregates smaller then 0.25mm were less than 10 percent for 1990 and less than 13 percent for 1991 (Figure 2.41).

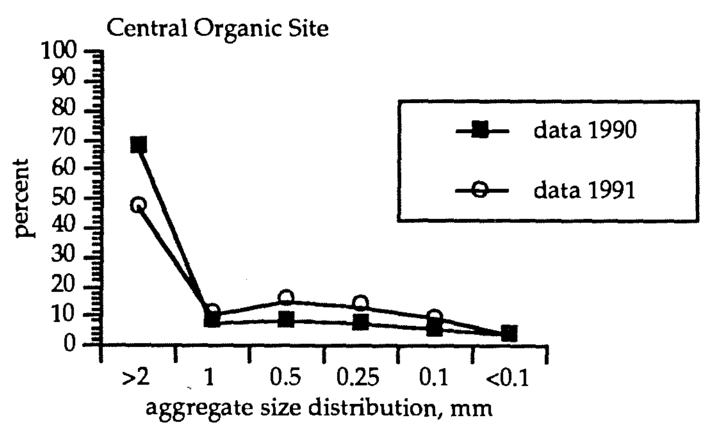


Figure 2.41. Soil aggregate size distribution for 1990 clover/fallow and 1991 soybean acreage.

In this organic farm agroecosystem, nitrogen entered the soil through atmospheric precipitation, decomposition of organic matter, and nitrogen fixation by leguminous crops such as clover and soybeans. There were no industrial nitrogen inputs into this farm system, but an estimated 81 lbs of nitrogen (N) was added with the plow-down clover; the estimated value of the soybean residue was 51 lbs N. No estimation was made for the N contributed by the legumes through nitrification. Soil tests conducted for this study in the spring and autumn of 1990 and 1991 show the level of free nitrate and ammonium to the 48-inch soil depth (Table 2.41).

Table 2.41. Summary table of soil physical and chemical characteristics for the central organic site.

Nutrients

Nitrate $mg\ kg^{-1}$	0-3	3-6	6-12	12-24	24-48
'90 spring	8.78	7.08	6.16	4.43	8.06
fall	32.17	18.62	7.07	4.79	4.56
'91 spring	4.86	4.32	7.75	5.88	2.67
fall	4..60	2.86	1.79	2.52	2.66
Ammonium $mg\ kg^{-1}$					
'90 spring	1.80	1.84	2.35	3.05	2.46
fall	2.40	2.31	3.39	2.56	2.42
'91 spring	4.03	3.29	2.82	2.58	2.48
fall	4.52	3.11	3.52	3.45	3.59
Phosphorus $mg\ kg^{-1}$					
'90 spring	12.0	8.5			
fall	11.5	5.0			
'91 spring	10.5	7.5			
fall	13.5	9.0			

Soil Physical Characteristics

Horizon Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A_p 0–9	clay loam.	weak SBK part to gran.	neutral	common	
A 10-17	clay loam.	weak SBK	neutral	common	
B_w 18-25	clay loam.	weak SBK	neutral	few	few fine yl.mtles.
B_k 26-31	clay loam	weak SBK	violent	few	few fine yl. mtles.
C 32-48	clay loam	massive	strong	none	many md.yl. mtles

	**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
'90	0.96g cm^3	7.6	3.88%	7425	0.91%	68
'91	0.94g cm^3	7.3	4.44%	955	0.94%	9

	Aggregate Stability
'90 spring	89%
'91 spring	95%

Abbreviations defined:

*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.

**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

The very fine particle lightfraction component of total soil organic matter was considerably different for the two years of the test (Table 2.41). The spring of 1990, when these tests were taken, was preceded by two years of drought. Springtails and mites continue to breakdown organic matter in times of drought and accumulated mineral N would become available for plants upon rewetting of the soil. The 1991 measurements show 0.56 % increase in organic matter due to the clover green manure crop.

The nitrogen mineralization and immobilization transformation cycle was affected by factors such as the residual nitrogen remaining from the previous year (Table 2.41), the current year's response to climatic factors such as precipitation and temperature, and the way in which all of these factors affect the biological system.

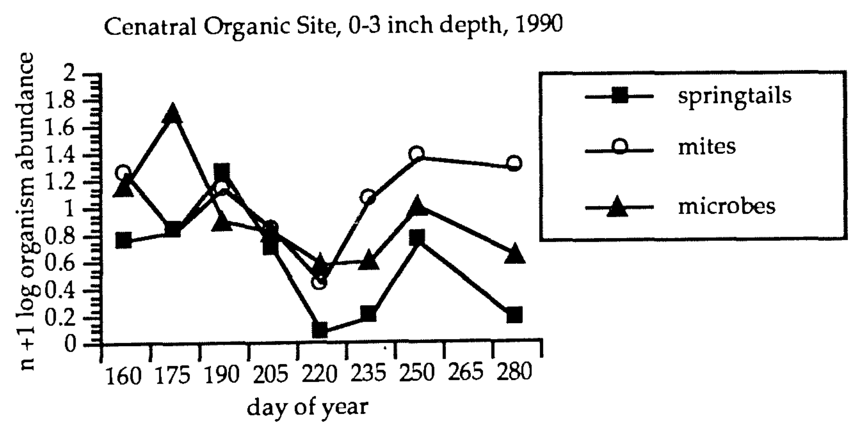


Figure 2.42. Soil fauna population measurements at one soil depth and eight sample dates for 1990. The crop grown on this site was clover/fallow. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg $^{-1}$ ammoniun for 1g dw soil.

In an attempt to quantify the effects of these dynamics on soil fauna (bacteria, mites and springtails) soil cores were extracted to a depth of 15 cm on eight separate days from June to September 1990 (Figure 2.42). The clover was disked down between sample days of year 160 (June 14) and 175 (June 24). The microbe population was at its highest level on day of year 175. There were repeated cultivations with 16 inch sweeps on daysof year 186 (July 5), 216 (August 4), 230 (August 18) and 281 (October 8). All soil fauna populations were at their lowest level on day of year 220 (August 8) and tended to increase by day of year 250 (September 7). There were 4

rainfall events between day of year 175 and 220 with the largest storm of 1.75 inches on day of year 232 (August 20). The mites increased to their highest population between the end of the summer disturbance and the tillage prior to freeze up. The population peak for the springtails was day of year 190 (July 9).

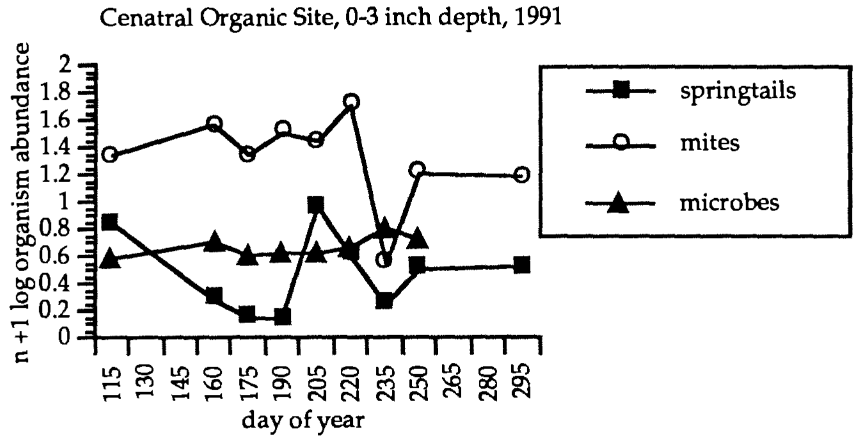


Figure 2.43. Soil fauna population measurements at one soil depth and nine sample dates for 1991. The crop was soybeans. Abundance springtails and mites = 1000 g dw soil; abundance microbes = mg kg $^{-1}$ ammonium for 1g dw soil.

Soil cores were extracted on nine separate days from April to October of 1991 (Figure 2.43). Between day of year 120 (April 30) and 160 (June 9) this field was cultivated, seeded and rotary hoed. Between day of year 160 (June 9) and 175 (June 24) this field was row cultivated twice. The peak microbe population was sampled on day of year 160 (June 9), mites on day of year 220 (August 8) and springtails on day of year 205 (July 24). Rainfall did not seem to cause the change in population between day of year 220 and 235 for the were many rainfall events earlier and of greater amounts than within this two week period. Average soil temperatures in the upper 3 inches 15 days prior to and after day of year 220 were the same, 64°F. The average soil temperatures for the next 15 day period (day of year 235-250 August 23-September 7) averaged 67.7°F.

In addition to microarthropods other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented.

Pitfall traps were collected on 7 successive sample dates for 1990 and 6 sample dates in 1991 (Figure 2.44). The predominant arthropods collected for 1990 and 1991 were as follows: spiders (4 families), beetles (11 families), flies (8 families), bees (6 families) and crickets.

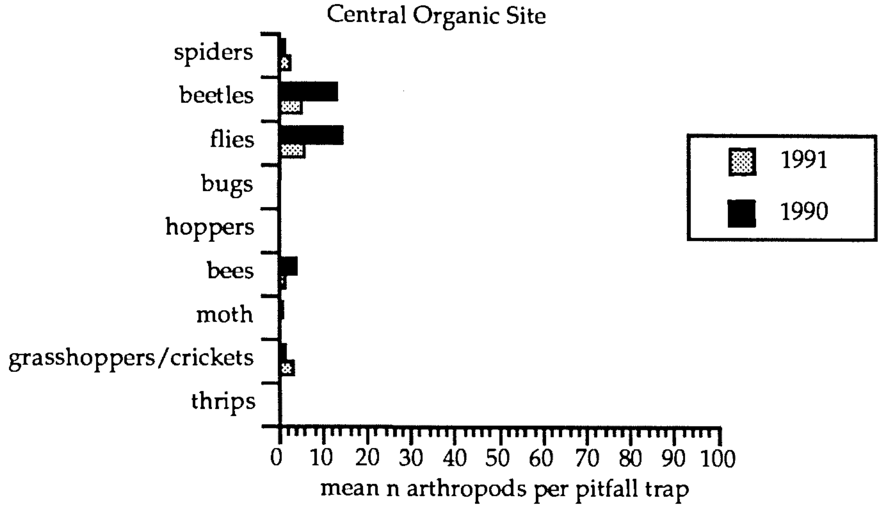


Figure 2.44. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 6 sample dates in 1991. Numbers are mean arthropods per trap for the total sampling period. Sample size =12 oz cup set at soil level for 4 consecautive days.

The predominant families of arthropods trapped in 1990 on the clover/fallow acres were different in some respects from those trapped in 1991 on the soybean acres. The ground spider *(Lycosidae)*, ground beetles *(Carabidae)* and carrion beetles *(Silphidae)*, long legged flies *(Dolichopodidae)* and buffalo gnats *(Simuliidae)*, common saw flies *(Tenthredinidae)*, and crickets *(Gryllidae)* were the families.found in abundance in 1990. Blister beetles *(Meloidae)* averaged 1.1 per trap for days of year 178 (June 27) and 189 (July 8) clover /fallow field despite the fact that the clover was disked down day of year 170 (June 19). Flies averaged 14.2 insect trap $^{-1}$ and beetles were an average of 13.2 insect trap $^{-1}$; other families averaged much less. In the 1991 soybean crop, the predominant insects trapped were daddy longlegs spiders *(Phalangida)*, ground beetles, buffalo gnats and flower flies *(Syrphidae)*, burrowing bees *(Halicitdae)* and crickets. Flies averaged 5.9 insects trap $^{-1}$ and beetles 5.1 insect trap $^{-1}$.

The Margalef index is an index of diversity. In this study it was used to test the diversity of insect families (Table 2.42). The higher the number the greater the diversity.

Table 2.42. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores from the central organic site.

Margalef Index of Pitfall Trap Insects

Central organic	**Predators**						**Herbivores**					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	3.04	3.74	5.04	2.80	3.94	3.72	0	0.54	0.24	0.18	0.18	0
1991	3.84	3.53	3.42	2.72	1.50	2.82	0.66	1.04	0.82	0.68	0.40	1.38
mean	3.44	3.64	4.23	2.76	2.72	3.27	0.33	0.79	0.53	0.43	0.29	0.68

Plant Species Present

The vegetation present (Table 2.43) consisted of forbs for both 1990 and 1991. The typical crops in rotation on this site for the two years of the study were red clover *(Trifolium pratense)* in 1990 and soybeans *(Glycine max 'NK')* in 1991. No weed species were observed in 1990. Green foxtail *(Setaria virdis)* was counted on 5 observation dates in 1991 with a high density on day of year 161 (June 10) of 4.2 sq ft^{-1} to zero observed on day of year 206 (July 25) to an increase of 3.2 mature plants sq ft $^{-1}$ rising above the soybean canopy on day of year 231 (August 19). Volunteer buckwheat was observed on the first sample date; other weed species observed in light densities

on two sample dates were redroot pigweed (*Amaranthus retroflexus*) and lambs quarters (*Chenopodium album*).

Table 2.43. Plants present in the central organic agroecosystem.

Central Organic System Species		
Trifolium pratense	*Amaranthus retroflexus*	*Chenopodium album*
Glycine max 'NK'	*Setaria virdis*	

Soil Moisture

Observations for soil moisture followed two years of drought. Available soil water at the 0-48 inch depth for November 6, 1989 in southwest Barnes County was estimated to be 2-4 inches (Extension SF 760, 1990). Winter and spring recharge for the central organic site yielded a total soil moisture of 11.59 inches for this study's tests on May 10, 1990 (Table 2.44).

Table 2.44. Total soil moisture at 0-48 inches sampling depth for spring and fall 1990 and 1991.

Soil Moisture

	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.47	0.70	1.40	2.67	6.35	11.59	14.3	16.7
fall	0.51	0.63	1.41	2.32	4.28	9.15		
'91 spring	0.30	0.34	0.95	2.27	4.44	8.30	12.6	13.0
fall	0.51	0.54	1.07	1.58	4.17	7.87		

Management

The objective of an organic farm management system is to use natural soil-building routines and crop rotation schemes instead of synthetic inputs, to supply nutrients, control weeds, insects and disease in the production of agronomic crops and livestock (Kirschenmann 1988). Typically a clover-fallow was included in the rotation every third year. For example the rotation starting in 1985 to 1991, the conclusion of the study, was as follows: wheat/corn/clover-fallow/rye/ buckwheat/clover-fallow/soybeans. The crop choice was made on the basis of field needs, anticipated weather and market demands.

The clover was underseeded with the crop prior to fallow year; in this example it was corn in 1986 and buckwheat in 1989. In 1990 the clover was allowed to reach blossom stage and was then disked down on June 19 (day of year 200). A field cultivator was used to work the field four times at intervals of 2 weeks throughout the summer with 1 cultivation just before freeze up. Cover estimates went from 95 percent just after disking to 14 percent before freeze up.

In 1991, the field was cultivated just prior to seeding with inoculated Northrup King soybeans into 36 inch rows at the rate of 1 bu a^{-1} the third week of May. Emergence was one week later. The first week of June the field was rotary hoed; one week later and again in 10 days the crop was row cultivated. There were no additional field operations until harvest.

Production and Resource Use Efficiency

The Net Primary Production (NPP) for the 1990 crop of clover was 3345 lbs a^{-1}; the estimated nitrogen resource was 81 lbs a^{-1}. The 1991 soybean crop was straight combined the end of September; NPP was 6450 lbs a^{-1} with an estimated grain yield of 1644 lbs a^{-1} (farmer field estimate 32 bu a^{-1}). Nitrogen removed with the crop was 93 lbs a^{-1}.

Using pre-season and post-season soil samples taken to a 48 inch depth, total gravimetric water, nitrate, and ammonium content were determined mathematically. Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen

plus nitrogen inputs, gross nitrogen and water use efficiencies were calculated (Figure 2.45 and 2.46).

There was 49 lbs a^{-1} of N present in the autumn tests of 1990 that were unavailable in the spring of 1991. Forty three pounds of this difference can be attributed to nitrates (NO_3 -) that were available in the plow layer after the plowdown of the clover that were not available in the spring tests (Table 2.41). Close comparison of the deeper sample values would indicate that the loss was not due to downward leaching. There were no tests to determine NO_3^- that may have been lost to the atmosphere or through runoff.

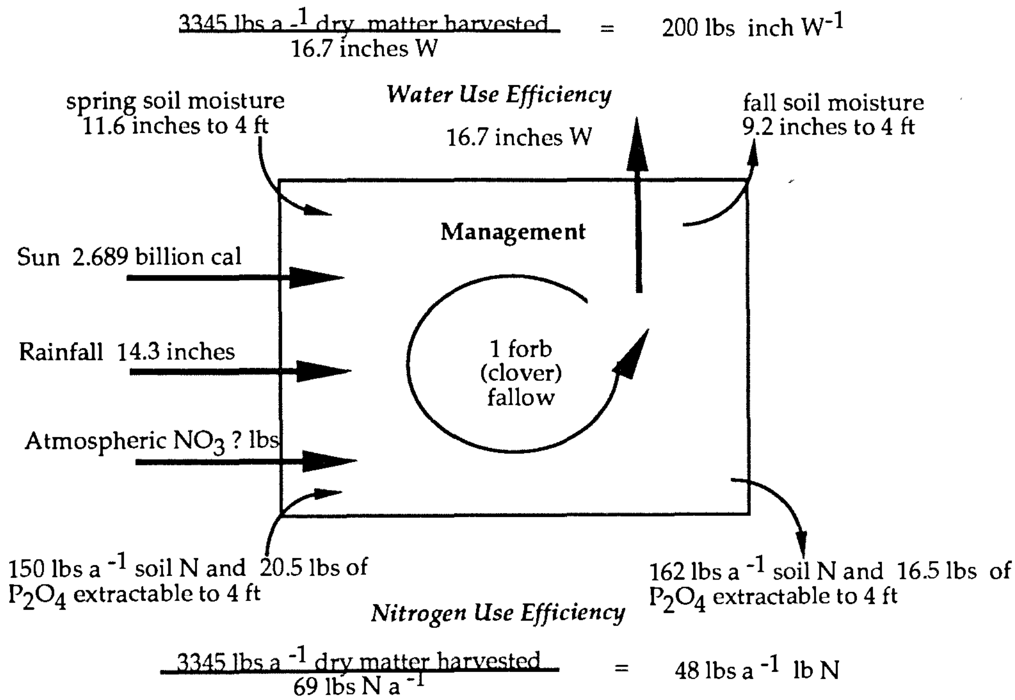


Figure 2.45. Gross inputs, outputs, and efficiencies from the central organic site during the summer of 1990. Spring soil tests were taken before the plow-down of the sweet clover June 19th.

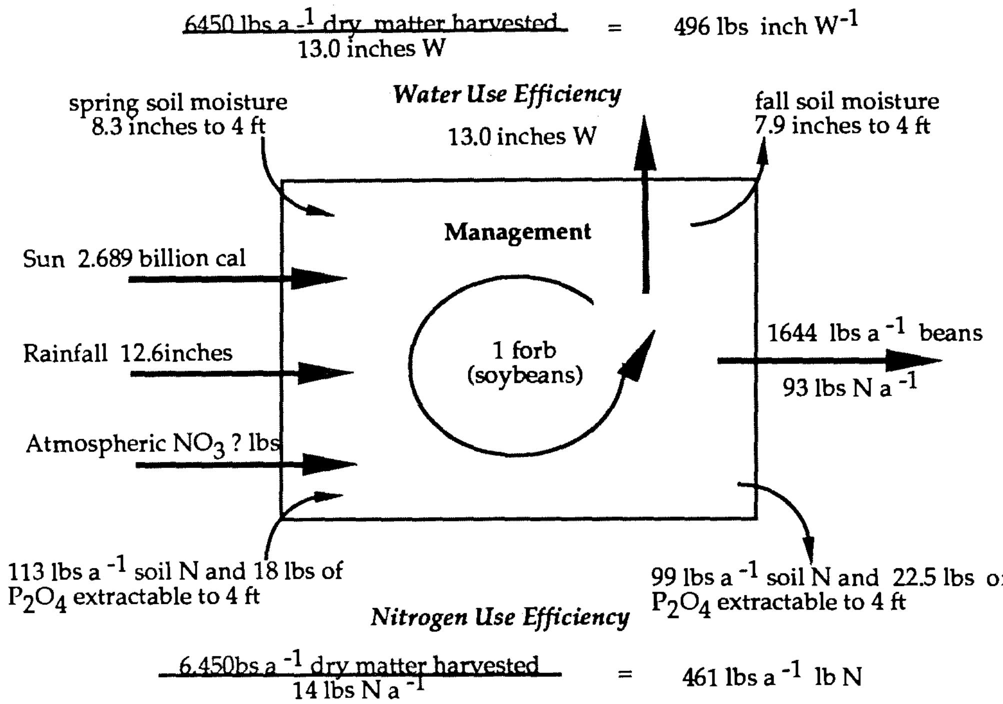


Figure 2.46. Gross inputs, outputs, and efficiencies from the central organic site during the summer of 1991.

WEST PRAIRIE SITE

West mixed grass prairie ecosystem

Geologic and Social History

The west prairie site, part of the unglaciated Missouri Plateau of the Great Plains Province, traces it's geological history back to the Paleocene period of the Cenozoic era when the Rocky Mountains were uplifting in the west. The very high mountains were cutting down rapidly and large rivers coursed eastward depositing alluvial materials (bedrock) comprising the Tongue River Formation of the Fort Union Group. This area, about the same as the present day Great Plains, was worn down to a near level surface.

The rivers such as the Little Missouri River joined the Yellowstone River which joined the Missouri which flowed northward into Hudson Bay; others flowed southward into the Gulf of Mexico. The Little Missouri was probably a much larger stream then. It flowed in a broad shallow valley which can be recognized in part as the highest of the four level terraces in the south unit of the Theodore Roosevelt National Park in Billings County. The west prairie site was located on one of these ancient terraces (Laird 1950).

The Missouri, Yellowstone and Little Missouri Rivers were diverted southward and southeastward by the advancing glacial ice which directed their flow into the Gulf of Mexico. The glacial ice forced the Little Missouri to make a great bend which made the river shorter and placed the mouth of the river at a considerably lower point.

The river began its down cutting action to carve the area in North Dakota known as the Badlands. The stream, flowing at a level, swung back and forth cutting first one side of the valley and then the other to form a relatively flat surface in the valley bottom along the stream; to leave terraces cut into bedrock; and to expose layers of shale, clays, sandstones, silts, sands and lignite. Lightening strikes frequently started the lignite on fire baking the shales, clays and sands into red rock locally called scoria. Heavy rains collapsed the burned out veins and the canyon walls eroded further. The Little Missouri River Valley today is 200 feet below the west prairie site (Laird 1950, Carlson 1983, and Bluemle 1977).

The Teton Sioux called the valley "the place where the hills look at each other"; the first white explorers impeded in their travel named it "bad-lands to travel through." From 6 to 16 miles wide the Bad Lands extend the course of the Little Missouri River. Herman Hagedorn writing for the North Dakota Workers of the Federal Writers' Project describes this area as follows, "Between the prairie lands of North Dakota and the prairie lands of Montana there is a narrow strip of broken country so wild and fantastic in its beauty that it seems as though some unholy demon had carved it to mock the loveliness of God" (WFWP 1938).

Early records indicate that indigenous people, perhaps the Crows (buffalo hunting nomads), were attracted to the area during moist times only to be driven out during periods of drought. In the 1850's the Teton Dakota Sioux were making their home in this country west of the Missouri. Coming from a woodland culture to the grasslands they had to modify all aspects of their life including changing their religion from the Grand Medicine Society based upon the abundance of herbs in the woods to the Sun Dance Ceremony created to call the bison. Plains culture meant horse culture, plains Indians were horse Indians; bison were the great wealth of the grasslands, and horses allowed the Teton Dakota to take that wealth easily and become rich (Robinson 1966).

The demographic map of North Dakota shows the origins of the Euro-Americans in this area to be Anglo Saxon with a few Irish. Hunters were attracted by the wildness of the terrain and the abundant game such as bison, elk ,deer, antelope, bighorn sheep, beaver, otter, bobcats, coyotes, prairie grizzlies, and mountain lions plus game birds.

Cowboys called Badlands Bill, Six Shooter Slim and Shy came from Montana and South Dakota with trail herds on their way to graze the eastern slopes of the Rockies; or were hired men from the large bonanza cattle ranches; or they came with the railroads or army all attracted by the abundant grass and winter shelter to be found among the buttes and along the river valley. Another notion of plains culture was developed and another notion of wealth established; it was free, exciting, lawless and adapted to the semi arid grassland.

The Teton Dakota Sioux, whose life completely centered on the bison, had a difficult time adjusting to the disappearance of the wild game. It was not surprising to learn that there was the Battle of the Badlands (1862) where the Teton Dakota clashed with the Euro-American Settlers; or in the 1870's when raided survey parties sought the army's protection from the Teton Dakota Sioux.

By 1885 ranchers had fully occupied the Little Missouri River Valley. From 1886 to 1887 cattle starved by the tens of thousands. The region's dry cycle gripped the lands once again overcoming the range with drought, grasshoppers, fire, and early winter with abundant snow. President Theodore Roosevelt was one of the ranchers caught by this drought cycle and it brought to an end his three year romance with North Dakota's Badlands (Palanuk 1979)

The badlands have undergone many periods of erosion and deposition which are most intense during periods of drought. Geologists document 4 separate periods of erosion and 3 periods of deposition. The new gullies in the badlands were cut to their present depth since 1936, the date of the last severe drought cycle (Bluemle 1977).

When President Roosevelt died in 1919, there were numerous proposals to establish monuments and memorials to his memory; North Dakota was no exception. Leading citizens of the state struggled with law, land procurement and politics for 28 years starting in 1919. The drought cycle of the 30's was the major factor in the acquisition of the land for the park.

The North Dakota Legislature in 1929 initiated 3 bills and set aside $200,000 to allow lands to be seized for failure to pay taxes, to purchase school lands, and to condemn additional lands required to make the park site. These Little Missouri River Valley lands, (71,191 acres), were ceded to the US Government. In 1932 the Director of the National Park Service said that the planned park was too big. This was the prevailing attitude until 1947 when the HR Bill 731 was successfully carried through congress by ND Representative Lemke and signed into law by President Harry S. Truman (Palanuk 1979).

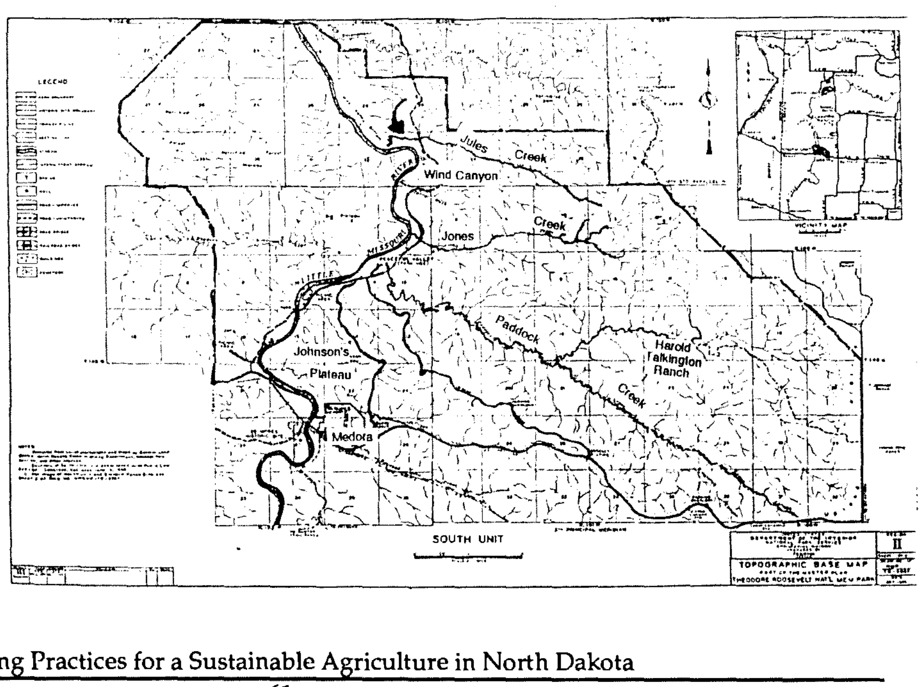


Figure 3.11. The south unit of the Theodore Roosevelt National Park. The arrow marks The location of the west prairie site.

The sampling regime for the study of the west prairie site consisted of an in-depth evaluation of a level one acre portion of a 5 acre field. Sen, the reference soil (Table 3.11), was verified by a soil scientist from the Soil Conservation Service of the USDA. The moderately deep well drained soil over soft bedrock was covered with native vegetation of west mixed prairie grasses. Wildlife used this area as a major pathway to access the Little Missouri River. The research team encountered bison on the site and coyotes were heard in the distance.

Soil Physical Characteristics

Measurements of the soil physical characteristics such as bulk density, wet aggregate strength and dry aggregate size were taken from the west prairie site in 1990 and 1991 (Table 3.11). Since the only disturbance to this site was from grazers moving through, the soil physical measurements remained the same for both years of the study. There was a difference (Figure 3.12) in the fine aggregates of less than 0.25mm size for 1990 (21 percent) and 1991 (15 percent).

Table 3.11. Summary table of soil physical and chemical characteristics for the west prairie site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	3.67	2.99	3.15	3.14	2.85
fall	4.15	2.57	1.99	1.64	2.02
'91 spring	2.37	1.51	0.48	0.62	0.17
fall	1.58	1.35	1.39	0.43	0.46
Ammonium mg kg^{-1}					
'90 spring	3.97	5.34	3.35	2.23	2.15
fall	1.96	1.45	1.42	1.19	0.95
'91 spring	12.02	11.28	7.19	5.06	3.15
fall	4.14	2.43	1.82	1.59	2.11
Phosphorus mg kg^{-1}					
'90 spring	5.5	4.0			
fall	4.0	6.0			
'91 spring	5.5	4.5			
fall	6.5	4.0			

Soil Physical Characteristics

Horizon Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A 0–7	clay loam.	firm md.SBK part to gran.	neutral	many	
B 8-13	silt clay loam.	firm md.SBK	neutral	common	
C_1 14-28	clay loam.	md.SBK	strong	few	
C_2 29-40	clay loam	massive	strong	few	light olivr gry.
C_3 41-46	loam	massive	strong	few	dark olive gry.

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
1.06g cm^3	7.5	3.46%	12760	0.76%	97
0.92 cm^3	7.5	5.12%	7500	0.68%	51

Aggregate Stability
95%
95%

Abbreviations defined:
*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

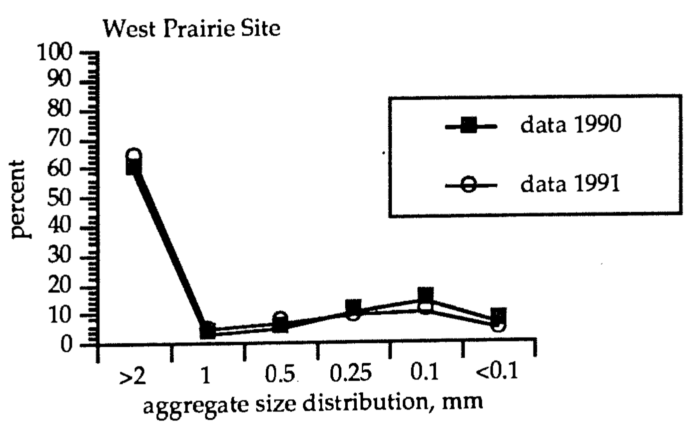


Figure 3.12. Soil aggregate size distribution for 1990 and 1991.

Soil Moisture

The amount of plant available soil moisture (Table 3.12) was an important factor in determining plant growth. Estimations of available soil water at the 0-48 inch depth for November 6, 1988 and 89 in Billings County were 0-2 and 2-4 inches respectively (Extension SF 760, 1990). Rainfall events in this region were intense and of short duration. More than 75% of the annual precipitation fell between April and September during violent thunder storms. (SCS 1990). For example, precipitation on the west prairie site for 1990 was 7.83 inches (Table 3.12) for the total growing season. Of the 14 rainfall events in June which yielded 3.67 inches of precipitation, 2.60 inches fell in 3 major events (Figure 3.13).

Soil moisture was determined at this site by gravimetric sampling to a depth of 48 inches during spring and autumn of 1990 and 1991 (Table 3.12). Precipitation estimates recorded at the nearest weather station during this period totaled 9.95 inches in 1991.

Table 3.12. Soil moisture at 0-48 inches sampling depth for spring and fall 1990 and 1991.

Soil Moisture

	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.37	0.56	0.87	1.07	1.87	4.74	7.83	9.2
fall	0.12	0.20	0.35	0.73	1.94	3.34		
'91 spring	0.55	0.81	1.11	1.66	1.38	5.51	9.95	8.4
fall	0.54	0.65	1.31	1.34	3.20	7.04		

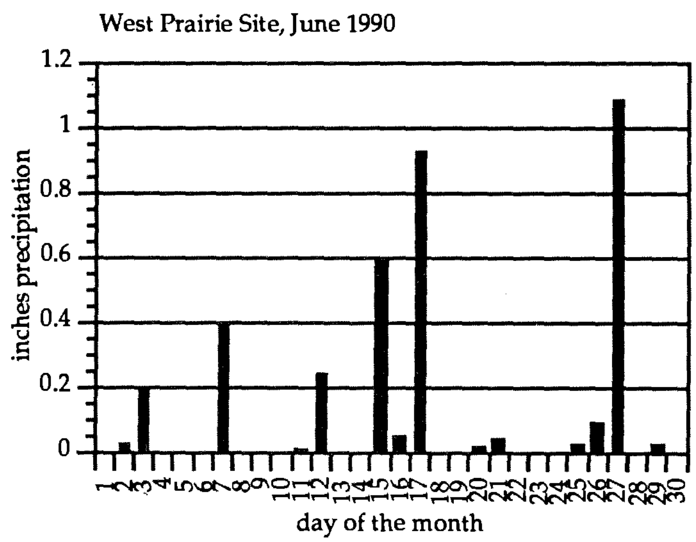


Figure 3.13 Rainfall events on the west prairie site for June, 1990. Rainfall on the Great Plains comes during violent thunderstorms.

Nitrogen Dynamics

In the west mixed grass prairie, nitrogen (N) enters the soil through atmospheric precipitation, release of organically bound nitrogen attached to particulate matter and nitrogen fixation by bacteria and blue green algae. Nitrogen exits the system through volatilization of ammonia, bacterial denitrification and nitrification followed by subsequent leaching.

In an attempt to trace the fate of N in the system, soil tests were conducted in the spring and autumn of 1990 and 1991 (Table 3.11). Comparison of the fall 1990 soil tests with the spring 1991 soil tests would indicate that 25 lbs of nitrate was lost from the upper 48 inches of the soil profile. The very fine particle lightfraction component of total spring soil organic matter for 1990 was twice that available for 1991 (Table 3.11). Soil fauna continue to breakdown organic matter into lightfraction components in times of drought as in 1989, but the mineralized N remains unused until soil moisture becomes available.

Nitrogen was also monitored in the above ground plant parts throughout the growing season (Figure 3.14). In most natural systems, N tends to reside more in living or decomposing plant tissue than in soil solution itself. Plant growth on the western prairie was described as surging between May and July (Palanuk 1979). Peak production on the west prairie site was day of year 160 (June 9th).

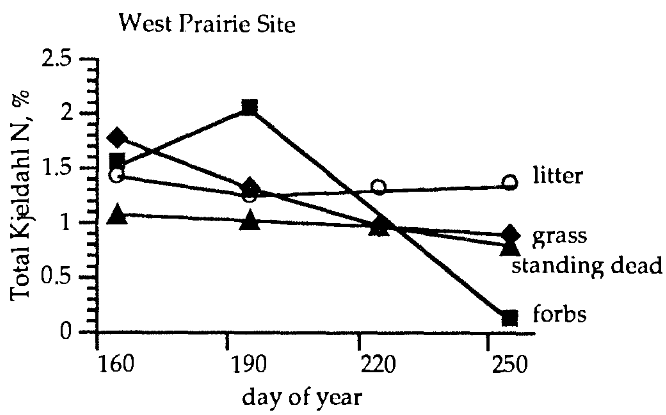


Figure 3.14. Total Kjeldahl N, % present in the above ground biomass at the west prairie site. Early ranchers believed the naturally cured grasses (standing dead) to be a good range for winter grazing.

The nitrogen mineralization and immobilization transformation cycle was affected by factors such as the residual N remaining from the previous year (Table 3.11), the current year's response to climatic factors such as precipitation and temperature and the way in which all of these factors affected the biological system.

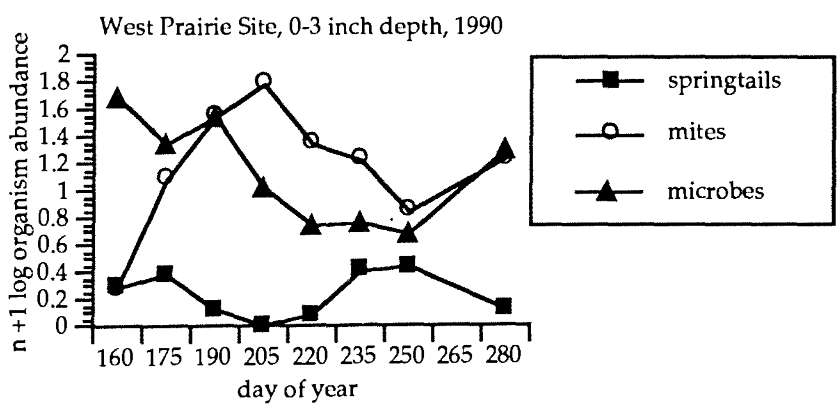


Figure 3.15. Soil fauna population measurements at one soil depth and eight sample dates for 1990. Abundance springtails and mites = 1000g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

In an attempt to quantify the effects of these dynamics on soil fauna (Bacteria, mites and springtails) soil cores were extracted to a depth of 15 cm on eight separate days from June to September 1990 (Figure 3.15). The population of microbes were highest in early spring, Day of year 160 (June 9th). After declining through the summer months, the populations increased on day of year 280 (October 7th). Springtails in 1990 were approximately even for two sample dates but the peak was on day of year 250 (September 7th). The peak mite population was observed on day of year 205 (July 24th); the bottom of the population decline was noted on day of year 250 (September 7th) followed by an increase in population on day of year 280 (October 7).

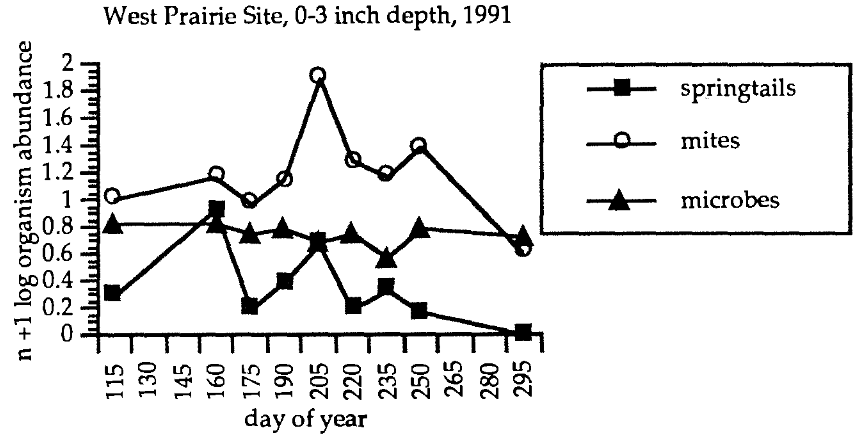


Figure 3.16. Soil fauna population measurements at one soil depth and 9 sample dates for 1991. Abundance springtails and mites = 1000g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

In 1991 there were 9 sample dates one earlier and one later than in the 1990 sampling (Figure 3.16). Microbe populations were more level throughout the 1991 season. Springtail populations rise and fall throughout the season with the highest point recorded on day of year 160 (June 6th). Mite populations peaked on the same day of year (July 24) in 1991 as they did in 1990.

In addition to microarthropods other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented.

Pitfall traps were collected on 7 successive sample dates for 1990 and 1991 (Figure 3.17). The predominant arthropods collected from the west mixed grass prairie site were as follows: spiders (8 families), beetles (17 families), flies (13 families) true bugs (3 families), bees (8 families), leaf hoppers (2 families), moth (2 families), grasshoppers and crickets. There was a higher number of families represented in 1991, the year of higher precipitation.

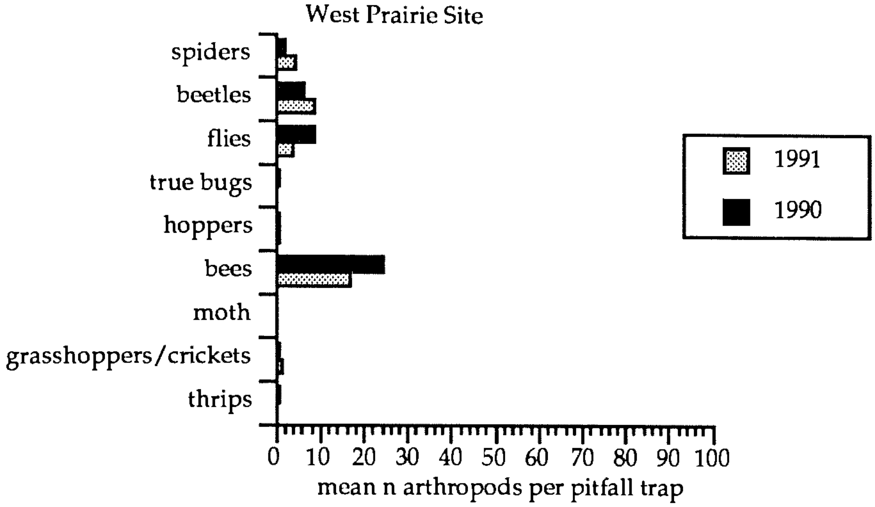


Figure 3.17. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 1991. Amounts represent the average number of arthropods per trap for the total sampling period. Sample size = 12 oz cup set at soil levlel for 4 consecutive days.

The predominant families of arthropods trapped in 1990 were as follows: 3 families of spiders in about equal number; grass spiders *(Agelenidae)*, hackeled band weaver *(Dictynidae)* and crab spider *(Thomisidae)*; ground beetles *(Carabidae)* and blister beetles *(Meloidae)*; buffalo gnats*(Simuliidae)*; plant bugs *(Miridae)*, leaf hoppers*(Cicadellidae)*; ants *(Formicidae)*; common thrips *(Thysanoptera)*; and grasshoppers *(Acrididae)*. The predominant families in 1991 were as follows: wolf spider *(Lycosidae)*, blister beetle *(Meloidae)*, black scavenger fly *(Sepsidae)*, seed bug *(Lygaeidae)*, leaf hopper *(Cicadellidae)*, ants *(Formicidae)*, and grasshoppers *(Acrididae)*.

The Margalef index is an index of diversity and in this study it was used to measure the diversity of insects families. The predators and herbivores of the west prairie ecosystem were the most diverse (Table 3.12) of all the sites evaluated as indicated by the high numbers

Table 3.12. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores from the west prairie site.

Margalef Index of Pitfall Trap Insects

West prairie	Predators						Herbivores					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	3.33	4.26	4.34	5.24	7.70	6.56	2.09	3.32	2.40	2.46	1.62	2.48
1991	6.35	4.00	5.46	4.66	5.04	4.80	2.84	3.36	2.04	0.40	0.90	0.66
mean	4.84	4.13	4.90	4.95	6.37	5.68	2.47	3.34	2.22	1.43	1.26	1.57

Plant Species Present

The vegetation present (Table 3.13) on the west mixed grass prairie site consisted of warm and cool season grasses, forbs, lichens, moss and bluegreen algae. The predominant warm season sod forming grass was blue grama *(Bouteloua gracilis)*. Two cool season bunch grasses predominated; they were green needle grass *(Stipa viridula)*, and needle and thread grass *(Stipa comata)*. The predominant forb in 1990 was yellow clover *(Trifolium campestre)*; in 1991 it was a species of aster *(Ericodies sp.)*. The predominant sedge was needle leaf sedge *(Carex eleocharis)*. The number of representative species counted for each year of the study varied considerably (Figures 3.18 and 3.19).

Table 3.13. Plants present in the west paririe ecosystem.

West Prairie System Species		
Agropyron smithii	*Carex heliophila*	*Hibiscus sp.*
Bouteloua gracilis	*Antennaria parvifolia*	*Lappula sp.*
Bromus Japonicus	*Artemisia dracunculus*	*Lygodesmia juncea*
Bromus techtorum	*Artemisia frigida*	*Opuntia polyacantha*
Festula octoflora	*Brassica sp.*	*Plantago purshii*
Kocleria cristata	*Chenopodium sp.*	*Polygala verticillata*
Stipa comata	*Dalea purpurea*	*Solidago sp.*
Stipa viridula	*Echinacea sp.*	*Taropogon dubius*
Carex eleocharis	*Ericodies sp.*	*Trifolium campestre*
Carex filifolia	*Grindella squarrosa*	*Xanthium sp.*
		Symphoricarpos occidentalis

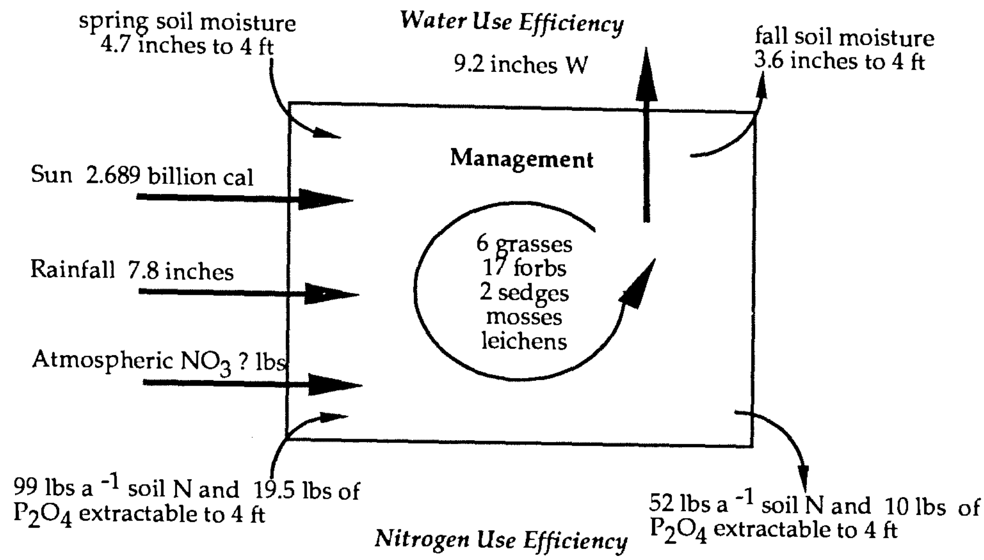
Management

The west prairie site was administered as a natural area. The primary objective of the management was to preserve representative natural environments and native biota as an integrated whole for scenic, educational and scientific values (Dept. of Interior July, 1984). Among the current projects at the park were soil and water and plant quality studies, soil mapping, integrated pest management (especially for leafy spurge control), and population control of native and introduced large animal species (Koeing project statement November 1991).

Production and Resource Use Efficiency

Native and introduced species, especially bison and wild horses *(Equies coballus)*, grazed the west prairie site in route to the Little Missouri River for water. Biomass samples were taken monthly to determine peak production and net primary production (NPP). During the 1990 growing season 1195 lbs of dry matter was produced with a net soil -N loss of 38 lbs. The NPP for 1991 was 1361 lbs with a net soil N loss of 47 lbs (Figure 3.18 and 3.19). It was estimated that 9 lbs of N resided in the grass, forbs and standing dead material in the autumn of 1990 and 10 lbs in 1991.

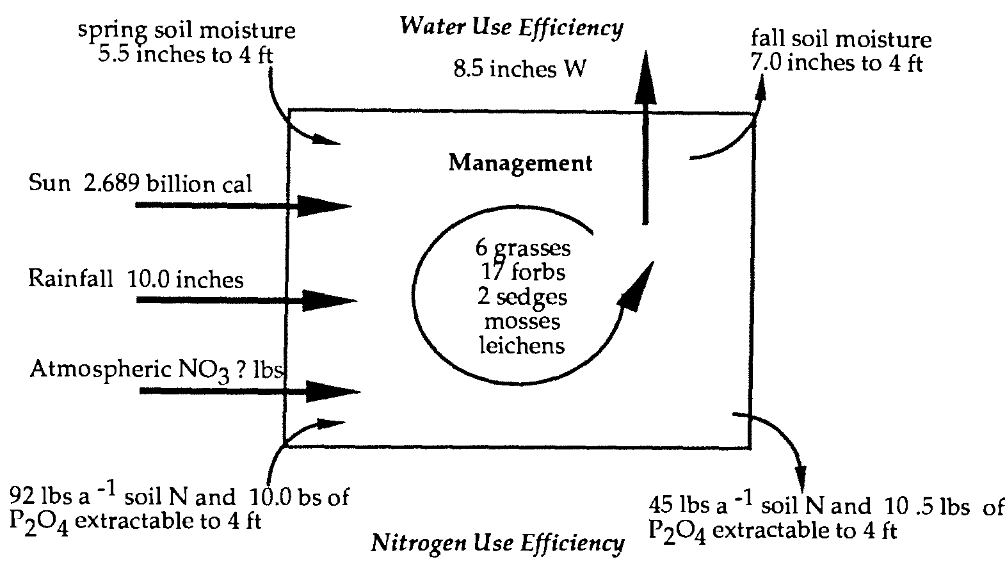
$$\frac{1195 \text{ lbs a}^{-1} \text{ dry matter harvested}}{9.2 \text{ inches W}} = 130 \text{ lbs inch W}^{-1}$$



$$\frac{1195 \text{ lbs a}^{-1} \text{ dry matter harvested}}{38 \text{ lbs N a}^{-1}} = 31 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 3.18. Gross inputs, outputs, and efficiencies from the west prairie site during the summer of 1990.

$$\frac{1361 \text{ lbs a}^{-1} \text{ dry matter harvested}}{8.5 \text{ inches W}} = 160 \text{ lbs inch W}^{-1}$$



$$\frac{1361 \text{ lbs a}^{-1} \text{ dry matter harvested}}{47 \text{ lbs N a}^{-1}} = 29 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 3.19. Gross inputs, outputs, and efficiencies from the west prairie site during the summer of 1991.

WEST CONVENTIONAL SITE
West mixed grass prairie ecosystem

Geologic and Social History

The west conventional site, located in a portion of Stark County, was part of the unglaciated Missouri Plateau section of the Great Plains Region. This ancient landscape comprised of the Golden Valley Formation was cast at the time of the climatic shift from warm temperate to subtropical. Bright colored clayey and sandy layers were deposited in lakes and rivers where fish, frogs, small birds, mammals, dinosaurs, and tropical vegetation once survived. This landscape carved by wind and water took millions of years to develop into today's topography of long escarpments, low buttes, mesas and rolling uplands drained by the Missouri River System. Over time, the uplands were covered with a natural wealth of drought resistant grasses of the mixed prairie type.

Located three miles from the west conventional site on the highest point in Stark County was the Geodetic Survey Station. Oil deposits underly the surface topography in the bedrock anticlines and synclines of the south central flank of the Williston Basin. Lignite, gravel and clay are also mined in Stark County (Robinson 1966, Trapp and Croft 1975, and Bluemle 1977).

Human occupation of the semi arid grasslands was more difficult than in the humid regions to the east. The bison followed the salt trails and the Indigenous Americans followed the bison as a food source. Early records dating back to the 1300's place the Mandan Indians in earthen huts and raising corn, beans, and squash in the river bottom acres along the Missouri River and its tributaries. By the 1700's they had abandoned the medicine culture of the woodlands to adopt the culture of the vision quest and bison hunting.

Their residence was followed by the Teton Dakota Sioux and then wave after wave of civilization followed: the explorer, fur-trader and hunter, the cattle-raiser and the pioneer farmer. Often these people scattered in times of drought only to return when the rains came. About half of the lands were suitable for crops and about half were best for grazing (Robinson 1966).

Concurrently in Europe during the 1700's, Germans were being enticed to emigrate to Russia by Catherine the Great to farm the steppe lands near the Black Sea while Empress Maria Theresa of Austria-Hungary welcomed huge numbers of German-speaking settlers into her dominion to farm in the Danube River Valley. The history of these Germans continued to parallel each other. In the late 1800's the German Russians emigrated to America prompted by loss of privileges and military conscription and the German Hungarians came for land and a promise of a better life. Both ethnic groups settled within six miles of each other in Stark County but there was no intermingling of the cultures for many years (Sherman et al 1988).

The history of farming the west conventional site began in 1906 with a homesteader of German Russian descent. He built a one room stone house and founded a grain-livestock farm which he operated for 45 years. He raised 17 children on his one-half section. When the homesteader retired, the land was transferred to the eldest son who died an untimely death. Several of the homesteader's grandchildren attempted to operate the farm but in 1967 the present owner took over the farm (Thompson et al 1978).

Born in America of German Hungarian parentage, the present owner had understandably inherited a love for woodlands reminiscent of the Black Forest in Germany. Because of his love for the forest environment, he has established a pine grove at every farm where he has resided. Characteristically, German Hungarians pursued a variety of occupations; even those who owned farmland would work part time in the nearest town (Sherman et al 1988). The owner of the west conventional site worked in the implement business and in chemical sales while he rented farm land , established his Black Angus herd, and invested in land. He has never had a chattel loan or

a mortgage on his land. He says of himself, "I had to scrounge to get what I got but then I was pretty careful with it."

In the late thirties he joined the Civilian Conservation Corps to work on projects in Sidney and Boyes, Montana (Thompson et al 1978). During the 1930's the Great Plains Region was a "dust bowl;" government programs were established to revitalize rural America. One program, the USDA Soil Conservation Service Great Plains Contract, consisted of a series of conservation practices targeted on this semi arid region. Under the terms of a farm plan designed specifically for the west conventional site, strip cropping, grass waterways, diversions, dugouts, and fences were established. A plan for pasture and hayland management included the seeding of native grasses and the fencing of this acreage so that livestock could range over 7 quarters of land subsequent to harvest. Stewardship has continued to be a priority with this farmer and he has won conservation awards on both the local and state levels.

Livestock has been this farmers hedge against the drought; he said it allowed him latitude in his decision making. In 1990 he stated that he was the least decided about what to plant. He described the times as being worse than the 1930's with back to back drought from 1987. He generally seeded his small grains in mid to late May after the rains had started. If he passed up the seeding in May, he would seed Sudan sorghum or Siberian millet for hay in July provided there was sufficient moisture. He raised tame hay and barley and hayed his native grass (every other year) for livestock feed . He carried a reproductive herd of 100 head of Black Angus.

The sampling regime for the study of the west conventional site consisted of an in-depth evaluation of a level one acre portion of a 13.7 acre field. The index soil (Table 3.21 soil physical characteristics) was Farland on the flat and Regent on the slope. These soils are deep well drained soils with slow to moderate permeability. They were selected by a soil scientist from the Soil Conservation Service of the USDA as the closest match available on this site to the reference soil, Sen, on the native prairie site

Soil Physical Characteristics

Measurements of the soil physical characteristics, bulk density, wet aggregate strength and dry aggregate size were taken from the west conventional site in 1990 and 1991 (Table 3.21). Surface soil samples from mid-July of 1990 and 1991 were separated for aggregate size distribution. On this west conventional site there was no difference in the soil particle aggregation despite one disking and 2 passes with 16 inch sweeps through the 1990 growing season as compared to one pass with a vibrashank and a seeder weeder proceeding the drill pass in 1991. In 1990, 10% of the soil particles were in the size category of less than 0.25mm while the soil supporting the wheat crop in 1991 had 6.8% less then 0.25 mm.

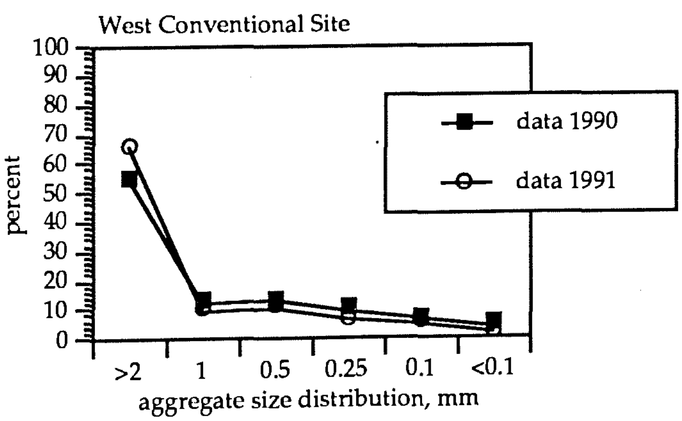


Figure 3.21. Soil aggregate size distribution for 1990 black fallow and 1991 wheat acreage.

Water stable aggregates of the west conventional site differed by year and by crop (Table 3.21). The aggregates from the 1990 black fallow acreage were 62% water stable; the aggregates from the 1991 wheat acreage were 96% water stable. The spring bulk density measurements of 1990 were an average taken prior the manure being worked into the 6 inch plow layer.

Table 3.21. Summary table of soil physical and chemical characteristics for the west conventional site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	18.56	20.03	15.13	5.17	6.64
fall	7.89	11.07	9.11	5.81	5.00
'91 spring	9.12	16.09	14.31	7.34	4.41
fall	11.70	14.12	9.46	5.53	3.88
Ammonium mg kg^{-1}					
'90 spring	3.73	3.91	4.16	2.78	2.90
fall	1.67	1.85	1.78	1.88	1.73
'91 spring	5.29	3.49	3.65	3.30	2.53
fall	3.65	1.66	1.91	1.76	1.50
Phosphorus mg kg^{-1}					
'90 spring	42.0	12.5			
fall	m	10.5			
'91 spring	55.5	13.5			
fall	47.5	15.5			

Soil Physical Characteristics

Horizon Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A_p 0–6	clay loam.	md.SBK part to gran.	neutral	many	
B_{t1} 7-14	clay	firm md.ABK	neutral	many	many clay films
B_{t2} 15-21	clay	md.ABK	neutral	common	few fine prominent orange mtles.many clay films
B_{k1} 22-35	silt clay	md.SBK	strong	few	few fine prominent orange mtles. $C_a$acc.
B_{k2} 36-42	clay	md.SBK	strong	few	few $C_a$acc..
C 42-48	clay	massive	strong	few	c.fine dst.yl.mtles.

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
1.29g cm^3	6.8	2.75%	3375	1.16%	39
1.05g cm^3	7.0	3.36%	940	1.36%	13

Aggregate Stability
62%
96%

Abbreviations defined:
*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

Soil Moisture

The amount of plant available soil moisture (Table 3.22) was an important factor in determining plant growth. On November 6, 1989 (Extension SF 760, 1990) available soil water in southwest Stark County at the 0-48 inch depth was estimated to be 1-2 inches; this was evidence of the previous drought conditions in the county. Rainfall events in this region were intense and of short duration. More than 75% of the annual precipitation occured between April and September during violent thunder storms (SCS 1990). For example, precipitation on the west conventional site for 1990 was 7.27 inches; records for May, June, and July of 1990 account for 6.73 inches of the total for the growing season. Of the 18 rainfall events in June of 1990 yielding 3.93 inches of precipitation, 3.09 inches occurred in 4 major events (Figure 3.22).

Soil moisture was determined at this site by gravimetric sampling to a depth of 48 inches during spring and autumn of 1990 and 1991 (Table 3.22). Precipitation estimates recorded at the nearest weather station during this period totaled 9.15 inches in 1991.

Table 3.22. Total soil moisture at 0-48 inch sampling depth for spring and fall of 1990 and 1991.

	Soil Moisture							
	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.55	0.74	1.12	1.17	3.10	6.68	7.27	7.6
fall	0.28	0.57	1.27	2.07	2.92	8.30		
'91 spring	0.22	0.31	0.91	2.61	4.25	8.30	9.15	12.0
fall	0.36	0.37	0.61	1.25	2.88	5.47		

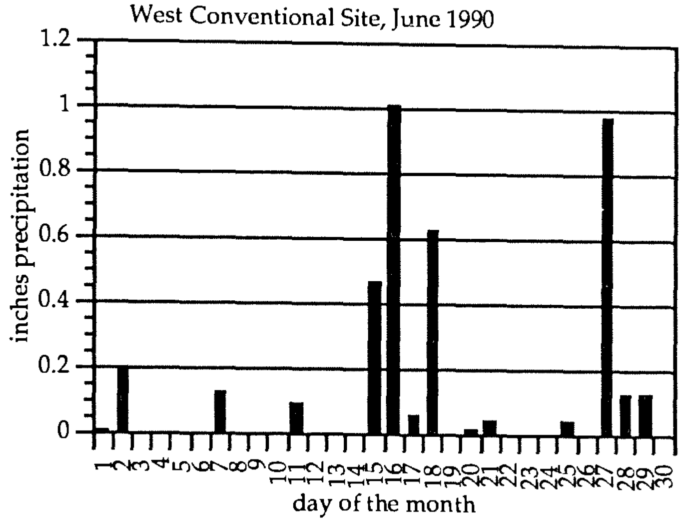


Figure 3.22. Rainfall events on the west conventional site for June, 1990. Rainfall on the Great Plains comes during violent thunderstorms.

Nitrogen Dynamics

In this conventional farm agroecosystem, nitrogen (N) entered the soil through atmospheric precipitation, decomposition of organic matter, and application of manure from the livestock operation, industrial fertilizer, and an unquantified amount of manure from the livestock ranging the lands after harvest.

Based on the farmer's experience, 10 tons of manure were applied to the west conventional site the autumn of 1989 prior to the black fallow of 1990. In 1991, 50 lbs a^{-1} of 11-52-0 were applied with the seeding of wheat. Spring and autumn soil tests conducted in 1990 and 1991 showed the level of free nitrate and ammonium to the 48 inch soil depth (Table 3.21).

Organic matter (OM) increased from 2.75% in 1990 to 3.36% in 1991 as the raw OM from the manure became part of the soil ogranic matter fraction. The very fine particle lightfraction component of total soil organic matter was considerably different for the two years of the test (Table 3.21). The spring of 1990, when these tests were taken, was preceded by two years of drought. Springtails and mites continue to breakdown organic matter in times of drought; mineral N accumulated would become available for plants upon rewetting of the soil.

The nitrogen mineralization and immobilization cycle was affected by factors such as the residual N remaining from the previous year, the amount, source, timing and method of application of the current year's infusion of N, the current year's response to climatic factors such as precipitation and temperature and the way in which all of these factors affect the biological system.

In an attempt to quantify the effects of these dynamics on soil fauna (bacteria, mites, and springtails) soil cores were extracted to a depth of 15cm on eight separate days from June to September, 1990 (Figure 3.23). The microbe populations hit a peak on day of year 160 (June 9) and subsequently declined to a low level until of year day 235 (August 23). Springtail populations peaked on day of year 220 (August 8) and remained relatively high for 45 days; this was measured 15 days after the lowest point on day of year 205 (July 24). The acreage had been cultivated with 16 inch sweeps on day of year 190 (July 8) and 236 (August 24). Springtail populations had declined to a considerable extent on the last sample date, day of year 280 (October 7). Mite populations peaked on day of year 205 and then declined until day of year 250 (September 7). Mite populations were increasing on day of year 280 the date of the last sample.

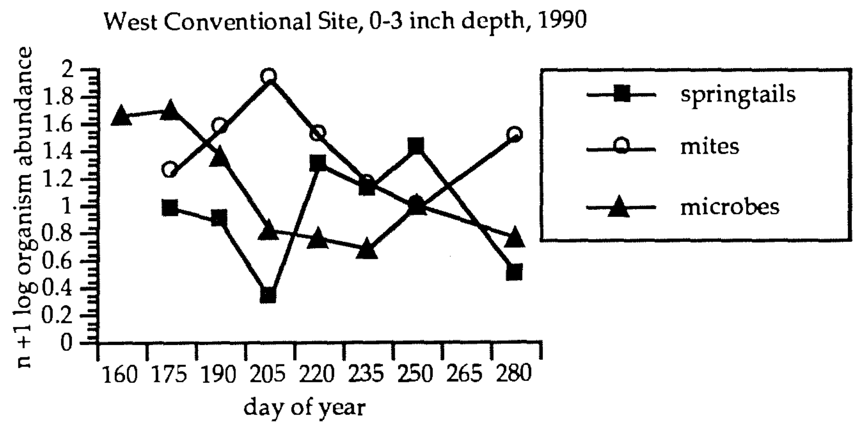


Figure 2.23. Soil fauna population measurements at one soil depth and eight sample dates for 1990. Abundance springtails and mites = 1000g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

In 1991 there were 9 sample dates (Figure 3.24); one earlier and one later than the 1990 sampling period. Microbe populations were more level throughout the 1991 season. Springtail populations peaked day of year 160 (June 9) and peaked again on day of year 235 (August 23). The lowest points were day of year 175 (June 24) and 280 (October 7). Mite populations peaked day of year 160 and remained relatively high throughout the season until autumn. There was no correlation between population cycle and soil temperature. Tillage ceased after day of year 139 (May 19).

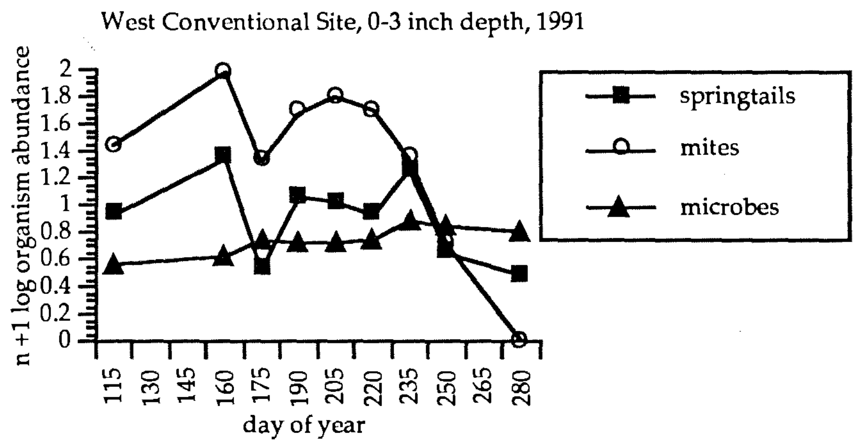


Figure 3.24. Soil fauna population measurements at one soil depth and nine sample dates for 1991. Abundance springtails and mites = 1000g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

In addition to microarthropods other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture is not well documented.

Pitfall traps were collected on 7 successive sample dates for 1990 and 1991 (Figure 3.25). The predominant arthropods collected from the west conventional site were as follows: spiders (10 families), beetles (25 families), flies (14 families), true bugs (3 families), bees (11 families), moths

(3 families, grasshoppers and crickets. There was a higher number of families represented in 1991, the year of higher precipitation.

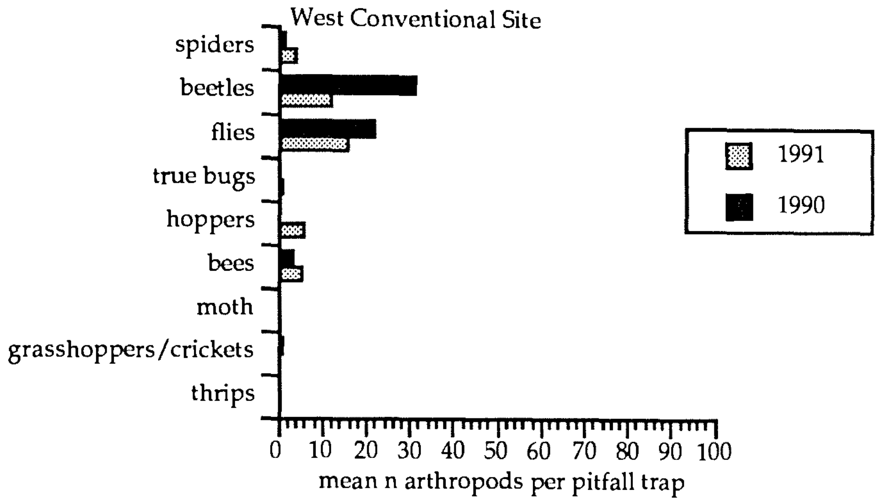


Figure 3.25. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 1991. Amounts indicate the average number of arthropods per trap for the total sampling period. Sample size = 12 oz cup set at soil level for 4 consecutive days.

The predominant families of arthropods trapped in 1990 were as follows: wolf spider *(Lycosidae)*, click beetle *(Elateridae)* and ground beetle *(Carabidae)*, buffalo gnat *Simuliidae)*, scentless plant bug *(Rhopalidae)*, leaf hopper *(Cicadellidae)*, and common sawfly *(Tenthredubudae)*. The predominant families in 1991 were wolf spider, jumping spider *(Salticidae)* and daddy longlegs *(Phalangida)*, click beetle and short winged mold beetle *(Pselaphidae)*, bee fly *(Bombyllidae)*, house fly *(Muscidae)* and black scavenger fly *(Sepsidae)*, assassin bug *(Reduviidae)*, aphid *(Aphididae)*, Ichneumon wasp *(Ichneumonidae)* and a parasite of other arthropods *(Chalcididae)*.

The Margalef index (Table 3.23) of diversity was used to evaluate insect family diversity. The higher numbers in 1991 reflect the diversity supported by the wheat crop as opposed to the 1990 black fallow.

Table 3.23. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores from the west conventional site.

Margalef Index of Pitfall Trap Insects

West conventional	Predators						Herbivores					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	1.68	4.32	3.06	2.94	4.88	3.06	0.74	0.42	0.16	1.18	0.50	1.50
1991	4.60	3.12	5.92	8.12	6.38	3.44	1.38	0.66	1.94	1.84	1.54	2.26
mean	3.14	3.72	4.49	5.53	5.63	3.25	1.06	0.54	1.05	1.51	1.02	1.88

Plant Species Present

The vegetation present (Table 3.24) on the west conventional site consisted of annual weeds and crop. The typical crop rotation for this site was black fallow and hard red spring wheat *(Triticum aestivum 'Amidon')*. In late June, kochia *(Kochia scoparia)* and wild oats *(Avena fatua)* were observed in the black fallow. No vegetation was observed for the remainder of the growing season. Early infestations of green foxtail *(Setaria virdis)* appeared soon after planting in 1991;

density increased until the wheat canopy covered the field in late June. Early June observations included red root pigweed *(Amaranthus retroflexus)*.

Table 3.24. Plants present in the west conventional agroecosystem.

West Conventional System Species			
Triticum aestivum 'Amidon'	*Avena fatua*	*Amaranthus retroflexus*	*Kochia scoparia*
Setaria virdis			

Management

Management practices on this site have consisted of a black fallow/wheat rotation. The fields were portioned into 20 rod strips. If there was autumn precipitation, then the wheat stubble was worked with 16 inch sweeps to open the ground to trap snow melt. Manure at the rate of 10 ton a^{-1} was transported from the farm lot during late fall. Starting in late May of 1990 the fallow was worked 3 times; first tillage was an offset disk to chop the weeds and the second and third passes (early July and late August) were 16 inch sweeps followed by a rod weeder. Soil Conservation Service estimates residue reduction by 50% after the use of an offset disk and 15% with each pass with the sweeps (Tech Guide ND 119). When this study began in 1990, the disking operation had been completed and our residue measurements were 43% cover. The cover estimation in October was 59%. The average residue measurement for the entire growing season was 48.8% with a standard error of 9.9%. On this dry site the residue from the 1990 spring application of manure did not break down despite repeated tillage.

Seeding was delayed in 1991 until late May to evaluate the precipitation patterns for that growing season. Two days before seeding the field was worked with a vibrashank. On May 19th untreated Amidon hard red spring wheat was sown at the rate of 65 lbs a^{-1}. Starter fertilizer (50 lbs of 11-52-0) was applied with the drill pass; a seeder weeder followed the drill. A post emergence aplication of 2,4-D low volume ester (6 lbs LVE) was applied 25 days after seeding.

Production and Resource Use Efficiency

There was no net primary production (NPP) estimated for the 1990 black fallow year. In 1991 the wheat was swathed (mid August) leaving very little stubble (5.8 inches). Ten days later the grain was combined. The NPP was 11,100 lbs. a^{-1} with 1671 lbs a^{-1} marketable grain (farmer field estimate 23 bu a^{-1}) and 740 lbs a^{-1} straw (farmer field est.1 round bale a^{-1}) removed for livestock bedding. N removed with the crop (51 lbs a^{-1}) and straw (7 lbs a^{-1}) was 58 lbs a^{-1}.

Using pre-season and post-season soil samples taken to a 48 inch depth, total gravimetric water, nitrate, and ammonium content were determined mathematically. Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen plus nitrogen inputs, gross nitrogen and water use efficiencies were calculated (Figures 3.26 and 3.27). There would appear to have been a loss of 65 lbs a^{-1} of N from the spring of 1990 to autumn but 40 lbs a^{-1} were recaptured in the spring samples of 1991. The net loss of 13 lbs a^{-1} from the surface 6 inches does not appear to have leached downward (Table 3.21). There were only 0.40 inches of precipitation conserved with the black fallow system.

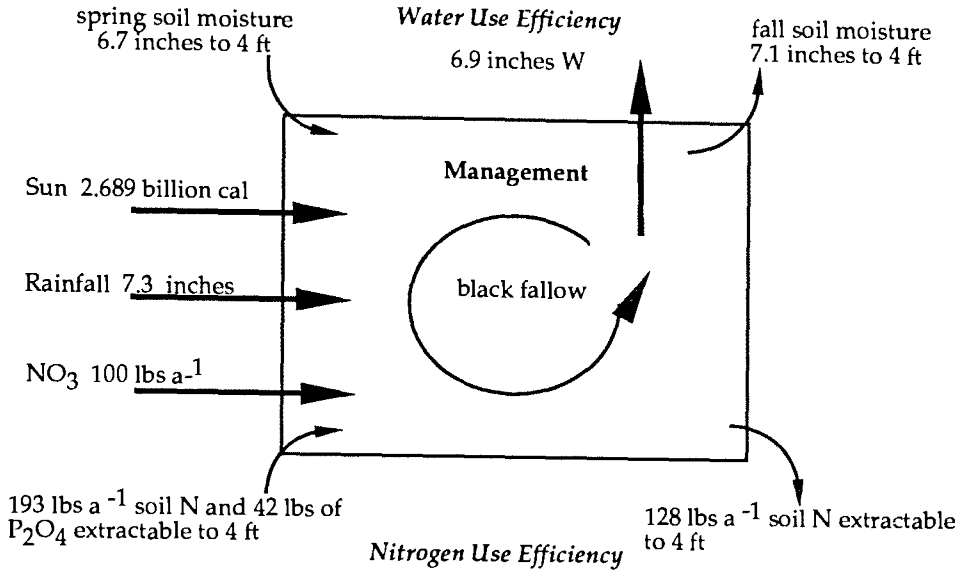
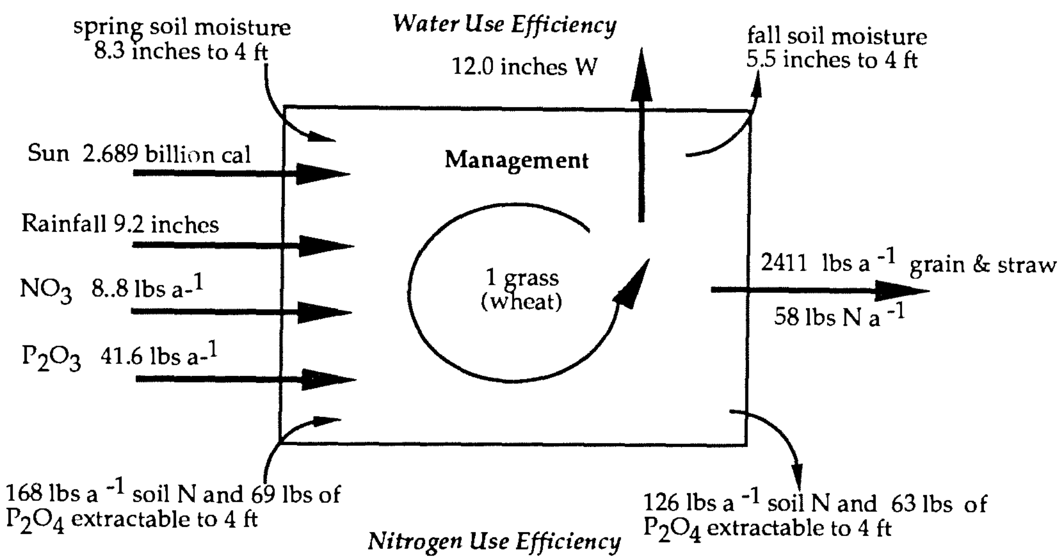


Figure 3.26. Gross inputs, outputs and efficiencies from the west conventional site during the summer of 1990. Manure equivalent of 100 lbs a^{-1} N was included in the 193 lbs a^{-1} N spring soil test.

$$\frac{11{,}100 \text{ lbs a}^{-1} \text{ dry matter harvested}}{12.0 \text{ inches W}} = 925 \text{ lbs inch W}^{-1}$$



$$\frac{11{,}100 \text{ lbs a}^{-1} \text{ dry matter harvested}}{42 \text{ lbs N a}^{-1}} = 264 \text{ lbs a}^{-1} \text{ lb N}$$

Figure 3.27. Gross inputs, outputs and efficiencies from the west conventional site during the summer of 1991. The 168 lbs a^{-1} of N measured with the spring soil test does not reflect the 8.8 lbs a^{-1} of N and 41.6 lbs a^{-1} P inputs.

WEST NO-TILL SITE
West mixed grass prairie ecosystem

Geologic and Social History

The Great Plains Province, part of the unglaciated Missouri Plateau, is one of the true natural divisions of the North American Continent (Willard 1921). Location of the west no-till site was in Golden Valley County, North Dakota, Great Plains Province. This site shares a common geologic history with the Badlands. The Tongue River Formation of the Fort Union group formed the surface topography of this site but there was no Little Missouri River to carve the badlands. Erosive action on the interbeded buff and light gray colored sand, silt, clay and lignite has shaped a topography of gently rolling uplands with scattered large hills, buttes, well-developed valleys, intermittent stream beds and lignite outcroppings.

Sentinel Butte, a land mark for the waves of people passing through North Dakota, rises 3550 feet above the prairie. The Battle of the Badlands was fought at her feet. The creeks as described by Willard (1921) were wide valleys bordered by steep bluffs eroded in the plateau surface. Water flows only during the season of heavy rains or melting snow causing currents that are very swift and able to carry heavy loads of effluvium. The parent material of the Tongue River Formation interacting with the drought resistant grasses of the mixed prairie type, have formed fertile soils suitable for range and cropland (Willard 1921, Bluemle 1977, and Carlson 1983).

Bison grazed the range and bison hunting nomads, the Crows, followed them into Golden Valley County. By the 1750's these indigenous people were driven out by the Teton Sioux who by the 1850's had to compete with the cowboys of the bonanza cattle ranches (Robinson 1966). "In 1900 the population was thinly scattered along the railroad and the back country was vacant except for an occasional ranch "(Dietz et al 1976).

Town building led by the merchants and land agents rather than farming by Euro-American settlers was the next step in the settlement of Golden Valley County. In 1880, the railroad reached Sentinel Butte and it was the territorial dividing line until 1885.

The second "boom" of growth in North Dakota's expansion extended from 1898 to 1915. It was comprised of first and second generation American farmers loaded into railroad boxcars with all their possessions (including livestock) to be deposited at a siding in the midst of the great plains. The arable unoccupied lands of the East were claimed and demand for food rose faster than production. Claims were filed on 1,000,000 acres of land a year and settlers covered the semiarid mixed grass prairie with small farms. The German Catholic Golden Valley Land Company owned a strip of land 30 miles long and 15 miles wide where they established collective settlement of farmers from Winnona County, Minnesota.

The grandfather of the present owner bought up a relinquishment to the home place in Billings County in 1905. (For a time the west no-till site was part Billings County and Golden Valley County was formed in 1912). He raised grain as a cash crop plus a few head of cattle, pigs, and chickens for home use. Grandfather, a graduate of the University of Minnesota, had a homestead in Winnona County, Minnestoa. He maintained ownership of his lands in Minnesota for some years after moving to North Dakota. He was a second generation immigrant whose father had homesteaded in Ohio.

The present owner of the west no-till site elected to attend his grandfather's alma matter, the University of Minnesota. Upon receiving his credentials as a scientist, he went to work for one of the Federal Government's most prestigious laboratories. But farming was in his blood; he maintained subscriptions to the farm journals; he talked farming to his friends at the lab. When the opportunity to go into farming with his dad was offered, his fellow scientists said go for it; he knew they were right and he did. At this time he bought the portion of land used in this study.

He farmed in the tradition of his grandfather and his father with 50/50 wheat/black fallow. He did back-grounding for beef calves until the introduction of the exotic breeds made that service obsolete; then he instituted an intensive hog operation. In 1980 this farmer stated that there was no rain and no crop and by spring of 1981 the lands were blowing hard enough to create a first rate "dust bowl". Carl F. Kraenzel (1955) in commenting on the drought of the 1930's said, "The chief measure of the non-adaptability of the humid area culture to Plains conditions is the movement of dust." Once again the "Better Farming" methods promoted by outsiders from humid agricultural regions failed the semiarid plains (Robinson 1966).

As member of the supervisory board for the Soil Conservation District, this farmer became aware of no-till farm practices and the Manitoba-North Dakota Zero Till Farmers Association. Training at workshops and meetings, support from the county agent, District Conservationist, the chemical companies and this farmer's own scientific training gave him the courage to initiate a no-till system on his farm in 1982. The last acre of tillage on his farm was in 1984. There were approximately 35,000 acres using this system in Golden Valley County in 1990 (Golden Valley SCS District Conservationist). The farmer of the west no-till site continues to be a leader not only in conservation tillage but all matters affecting land stewardship by serving on local, state and national boards and committees concerned with conservation.

The sampling regime for the study of the west prairie site consisted of an in-depth evaluation of a level one acre portion of a 76 acre field. The soil nearest to Sen, the reference soil, was Golva (Table 3.31) as verified by a soil scientist from the Soil Conservation Service of the USDA. It was a deep well drained soil formed in silty alluvium.

Soil Physical Characteristics

Measurements of the soil physical characteristics, bulk density, wet aggregate strength, and dry aggregate size were taken from the west no-till site in 1990 and 1991 (Table 3.31). Surface soil samples from mid-July of 1990 and 1991 were separated for aggregate size distribution. In 1990 and 1991, less than 10% of the soil particles were in the size category of less than 0.25 mm on this no-till site (Figure 3.31). Other tests conducted on this site were nitrogen (N), phosphorus (P), pH, organic matter, and the lightfraction portion of organic matter (Table 3.31).

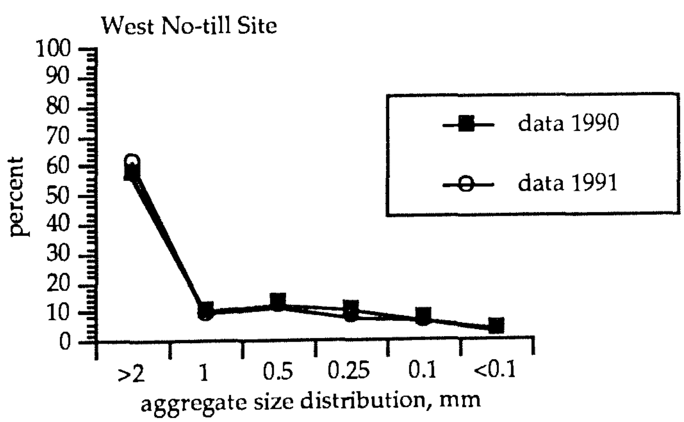


Figure 3.31. Soil aggregate size distribution for 1990 wheat acreage and 1991 chemical fallow.

Table 3.31. Summary table of soil physical and chemical characteristics for the west no-till site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	13.79	7.97	9.79	8.83	37.65
fall	7.51	5.38	3.27	8.25	18.48
'91 spring	3.01	2.00	3.44	4.19	16.92
fall	7.39	4.39	5.54	3.07	12.20
Ammonium mg kg^{-1}					
'90 spring	2.40	3.84	2.17	2.19	2.05
fall	1.70	1.57	1.42	1.33	1.30
'91 spring	9.59	11.66	6.21	5.24	4.53
fall	2.17	1.25	1.46	1.28	2.10
Phosphorus mg kg^{-1}					
'90 spring	11.0	7.0			
fall	10.0	7.5			
'91 spring	14.5	6.0			
fall	13.0	6.0			

Soil Physical Characteristics

Horizon	Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A_p	0–6	silt clay loam.	md.SBK part to gran.	neutral	many fine	
B_w	7-11	csilt lay	md.SBK	neutral	fine	slightly sticky
B_{k1}	12-17	silt clay	md.SBK	strong	few	slightly sticky
B_{k2}	18-30	silt clay	massive	violent	none	$C_a$acc.
B_{k3}	31-39	silt clay loam	massive	violent	none	$C_a$acc..
C	40-48	clay	massive	strong	none	br.,bedrock , $C_a$acc.

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
1.06g cm^3	8.1	3.10%	3140	1.27%	40
1.0.7g cm^3	7.8	3..86%	3880	0.72%	28

Aggregate Stability
79%
79%

Abbreviations defined:
*SBK = subangular blocky; gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

Soil Moisture

The amount of plant available soil moisture (Table 3.32) was an important factor in determining plant growth. In the region of the west alternative tillage site, available soil water as estimated by the North Dakota Extension Service (EXT SF 760, 1990) on November 6, 1989 was 4 inches. Where standing residue was left to trap the snow such as on this no-till site, the Extension Service estimates additional 1-2 inches of stored water.

Table 3.32. Total soil moisture determined at this site by gravimetric sampling to a depth of 48 inches for spring and fall of 1990 and 1991.

Soil Moisture

	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.53	0.50	1.11	1.65	3.98	7.77	5.91	6.8
fall	0.24	0.26	0.69	1.46	4.19	6.84		
'91 spring	0.59	0.77	1.59	2.36	3.86	9.17	18.17	13.9
fall	0.63	0.73	1.55	3.34	7.20	13.45		

Total spring soil water 1990 estimates for this study were 7.77 inches (Table 3.32). Rainfall events in this region are intense, of short duration, and frequently accompanied by hail. More than 75% of the annual precipitation occurs between April and September during violent thunder storms (SCS 1990). For example, precipitation on the west no-till site for 1990 was 5.91 inches; records for May, June, and July of 1990 show 4.53 inches of the total rainfall for the growing season. Of 8 rainfall events in June of 1990 yielding 2.83 inches of precipitation, 2.11 inches fell in 3 major events (Figure 3.32).

Rainfall in 1991 was 3 times (18.17 inches) that of 1990 (5.91 inches) reaching the upper limits for the Glova soil type (SCS Record ND0085). Teare and Peet (1983) suggest that 30% of precipitation enters into the drainage systems or percolates deep into ground water storage whereas 70% returns to the atmosphere through evaporation or transpiration through vegetation. (The west no-till site was under chemical fallow in 1991). Water in excess of field capacity percolates downward carrying available nutrients in solution.

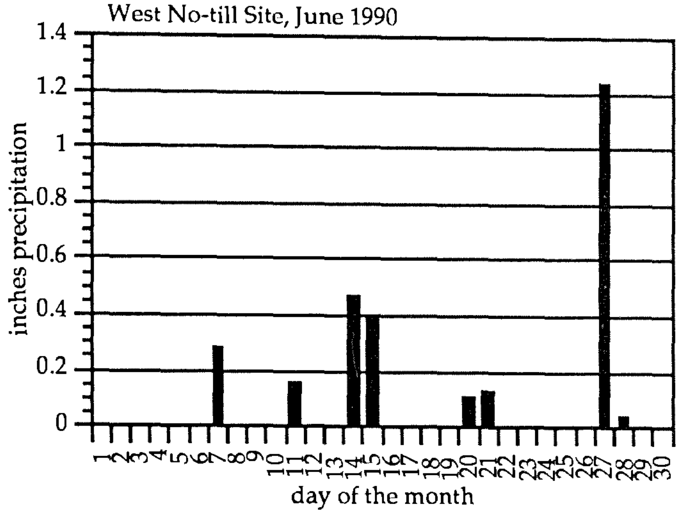


Figure 3.32. Rainfall events on the west no-till site for June, 1990. Rainfall on the Great Plains comes during violent thunderstorms.

Nitrogen Dynamics

In this no-till agroecosystem, nitrogen (N) entered the soil through atmospheric precipitation, decomposition of organic matter, application of industrial fertilizer and small amounts of manure produced by pigs (manure used on sites nearest home place).

The farmer of the west no-till site subscribed to a soil testing service which conducted tests to the 24 inch level during the autumn for the past several years. The soil test lab stated that there was 64 lbs a^{-1} N in the top 24 inches of soil profile. Based on a 40 bu a^{-1} wheat yield goal (farm history 34 bu a^{-1}) the laboratory recommended he apply 35 lbs a^{-1} N, 20 lbs a^{-1} P, and no potassium (K). There was a further note on the report that the application of 20 lbs a^{-1} of K to small grain will sometimes increase plumpness and possibly yield. The farmer applied 100 lbs of 32-14-6 from the drill box at seeding. Soil tests conducted for this study in the spring prior to seeding in 1990 found similar N (nitrate) levels in the upper 24 inches of the soil (Table 3.31); however at the 24 to 48 inch level there was 301 lbs a^{-1} of N (nitrate) out of reach of the potential wheat crop.

Once the deep nitrogen problem was determined the farmer wanted to change his small grain rotation to include deeper rooting crops but unfortunately he was locked into a wheat rotation for the next four years. The producers of chlorsulfuron (Glean ™), a broadleaf weed control, had rushed to get registration on the product so they could capture the booming no-till market; it turned out that they did insufficient research to determine residual effects. This farmer had a difficult time finding sufficient untreated acreage for the production of barley for his pigs.

The nitrogen mineralization and immobilization cycle was affected by factors such as the residual N remaining from the previous year, the amount, source, timing and method of application of the current year's infusion of N, the current year's response to climatic factors such as precipitation and temperature and the way in which all of these factors affect the biological system.

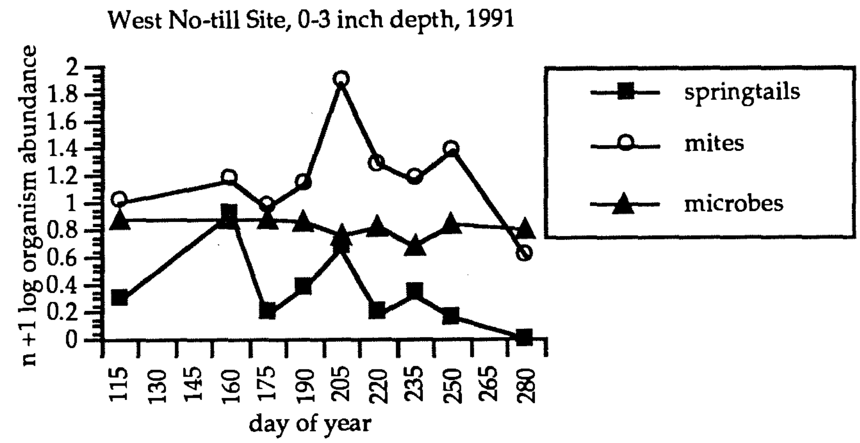


Figure 3.33. Soil fauna population measurements at one soil depth and eight sample dates for 1990. The crop grown on this site was wheat. Abundance springtails and mites = 1000g dw soil; abundance microbes = mg kg $^{-1}$ ammonium for 1 g dw soil.

In an attempt to quantify the effects of these dynamics on soil fauna (bacteria, mites, and springtails) soil cores were extracted to a depth of 15 cm of eight separate days from June to September, 1990 (Figure 3.33). The highest microbe population was measured on the first sample date, day of year 160 (June 9) and the lowest measurement was on day of year 220 (August 8). The population remained at this level for 30 days. Springtail populations were at a low point on day of year 175 (June 24) and again in the autumn (day of year 280, October 7); the population peaked on day of year 205 (July 24).

In 1991 there were 9 sample dates (Figure 3.34); one earlier and one later than the 1990 sampling period. Microbe populations were more level throughout the 1991 season. Springtail populations peaked day of year 160 and the lowest population levels were measured in the early spring, day of year 115 (April 25) and late autumn, day of year 280. Mite populations were the highest in mid summer, day of year 205, and the lowest in the autumn, day of year 280.

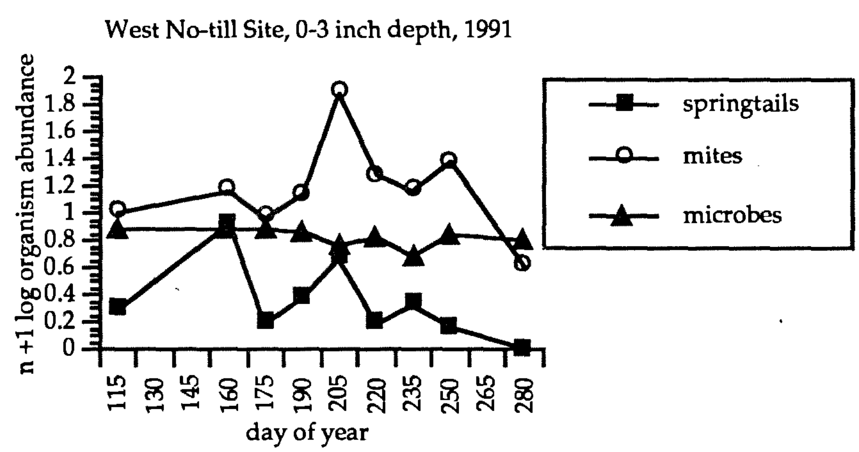


Figure 3.34. Soil fauna population measurements at one soil depth and nine sample dates for 1991. The acreage was used for chemical fallow. Abundance springtails and mites = 1000g dw soil; abundance microbes = mg kg $^{-1}$ ammonium for 1 g dw soil.

In addition to microarthropods other arthropods were quantified to obtain a better understanding of the biodiversity of the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture in not well documented.

Pitfall traps were collected on 7 successive sample dates for 1990 and 1991 (Figure 3.35). The predominant arthropods collected from the west no-till site were as follows: spiders (9 families), beetles (20 families), flies (10 families), true bugs (3 families), bees (10 families), moths (3 families), crickets (13 per trap in 1990) and a few grasshoppers. Reportedly there had been intense grasshopper infestation from 1985 to 1988. The farmer sprayed (4 oz a^{-1} carbofuran, Furadan 4F ^{TM}) four times in 1987 and though grasshopper pressure continued in 1988 there was no evidence of grasshoppers in 1989. There was more diversity among the beetles, flies and bees in 1991, the year of the chemical fallow and high precipitation, than there was in the 1990 wheat crop.

The predominant families of arthropods trapped in 1990 were as follows: wolf spider *(Lycosidae)* and crab spider *(Thomisida)*, ground beetle *(Carabidae)*, longlegged fly *(Dollichopodidae)* and buffalo gnat *(Simuliidae)*, burrow bees *(Halicitdae)*, and ghost moths *(Hepialidae)* and orange tip butterflies *(Pieridae)*. In 1991 there were few crab spiders trapped; the largest numbers of beetles were click beetles *(Elateridae)* and carrion beetles *(Silphidae)*; the flies were bee fly *(Bombyliidae)* and black scavenger fly *(Sepsidae)*. In addition to the burrow bee, leaf cutting bees *(Megachili)* were observed in 1991.

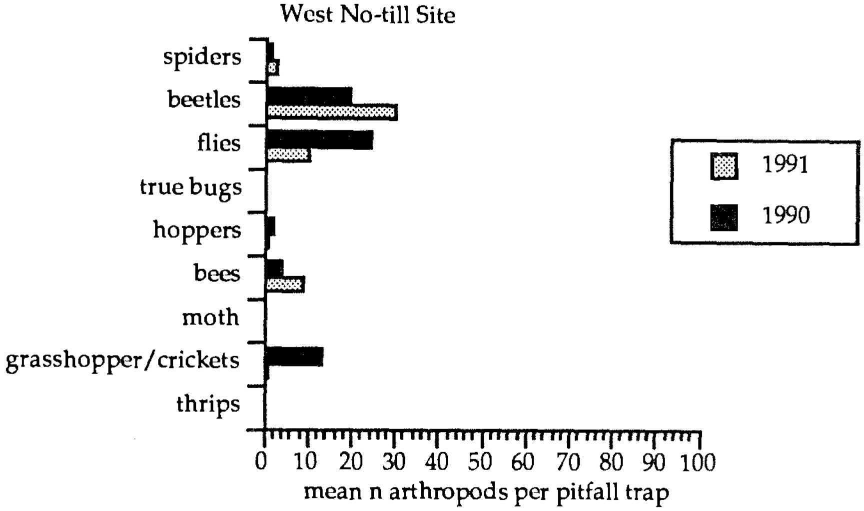


Figure 3.35. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 1991. Amounts indicate the average number of arthropods per trap for the total sampling period. Sample size = 12 oz cup set at soil level for 4 consecutive days.

The Margalef index is an index of diversity. In this study it was used to test the diversity of insect families of predators and herbivores; the higher numbers reflect higher diversity.

Table 3.33. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores from the west no-till site.

Margalef Index of Pitfall Trap Insects

West no-till	Predators						Herbivores					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	3.98	5.34	4.88	3.06	4.40	4.26	0.81	0.51	1.08	1.65	1.46	1.38
1991	8.95	4.70	7.76	6.74	4.69	5.64	4.11	0.84	4.72	2.56	0.78	1.16
mean	6.47	5.02	6.32	4.90	4.55	4.95	2.46	0.68	2.90	2.11	1.12	1.27

Plant Species Present

The vegetation present (Table 3.34) on the west no-till site consisted of crop, annual, and perennial weeds. The typical crop rotation for this site was chemical fallow/small grain/small

grain/chemical fallow. There were no weeds observed in the hard red spring wheat *(Triticum aestivum 'Stoa')* crop in 1990. Weeds observed in the chemical fallow year were as follows: volunteer grain *(Triticum aestivum)*, flixweed *(Descurainia sophia)*, field bindweed *(Convolvulus arvensis)*, green foxtail *(Setaria virdis)*, kochia *(Kochia scoparia)*, wild oats *(Avena fatua)*, and redroot pigweed *(Amaranthus retroflexus)*.

Table 3.34. Plants present in the west no-till agroecosystem.

West No-till System Species			
Triticum aestivum 'Stoa'	*Avena fatua*	*Amaranthus retroflexus*	*Convolvulus arvensis*
Descurainia sophis	*Kochia scoparia*	*Setaria virdis*	

Management

The objective of no-till farm management is to make as few trips across the field as possible, disturb the stubble mulch as little as possible to control wind and water erosion and maintain or increase production in the process (Proceedings, Conservation Tillage 1990). The management practices on this site have consisted of a rotation of chemical fallow/small grain/small grain/chemical fallow.

Wild oat control of 12.5 lbs a^{-1} triallate (Far-Go TM) was applied the autumn of 1989. Seeding was delayed (third week of May) until the soil temperatures were sufficiently high to assure good germination of the wheat. Prior to seeding, a preplant burn-down of weeds was used. It consisted of a herbicide combination of 12 oz a^{-1} glyphosate and 8 oz a^{-1} of 2,4-D low volume ester (6 lbs LVE). Two bushels a^{-1} Stoa wheat treated with 2-3 oz cwt^{-1} carboxin (75% Vitavax TM) was seeded double row (9 inch spacing) with a Haybuster Drill pulled with a JD 6030 tractor. Fertilizer at the rate of 100 lbs a^{-1} of 32-14-6 was applied with the drill pass. This acreage was sprayed a third time in late June for broadleaf weed control using 1/6 oz a^{-1} tribenuron (Express TM) and 8 oz a^{-1} 2,4-D (6 lb LVE).

Chemical fallow in 1991 consisted of three sprays with essentially the same combination of herbicides as follows: 12 oz a^{-1} glyphosate and 8 oz a^{-1} 2,4-D, with 1/2% by volume surfactant and 0.5 lbs a^{-1} ammonium sulfate. This herbicide formulation was applied on May 31 (day of year 151), July 14 (day of year 195), and July 28 (day of year 209). On July 14 the ammonium sulfate was omitted (unavailable at the time of spraying); ambient temperatures were very high (98^{o}F) and the kochia did not respond to the chemicals. On July 28, 8 oz a^{-1} dicamba (Banvel TM) was added to the formulation and the acres were resprayed.

Production and Resource Use Efficiency

On June 22 the no-till site was subjected to an ice and hail storm. The 1990 wheat was custom combined on August 27; the harvestable yields from this acreage were 30% less than the average field history (34 bu a^{-1}). Net primary production (NPP) was 3609 lbs a^{-1} with 931 lbs a^{-1} marketable grain (farmer field estimate 24 bu a^{-1}). Nitrogen removed with the crop was 28 lbs a^{-1}. There was no vegetative harvest from the acreage in 1991. Field cover measurements taken on June 6 (day of year 157) were 70%; field cover measurements taken on August 29 (day of year 241) were 34%.

Using preseason and post-season soil samples taken to a 48 inch depth, total gravimetric water, nitrate, and ammonium content were determined mathematically. Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen plus nitrogen inputs, gross nitrogen and water use efficiencies were calculated (Figures 3.36 and 3.37).

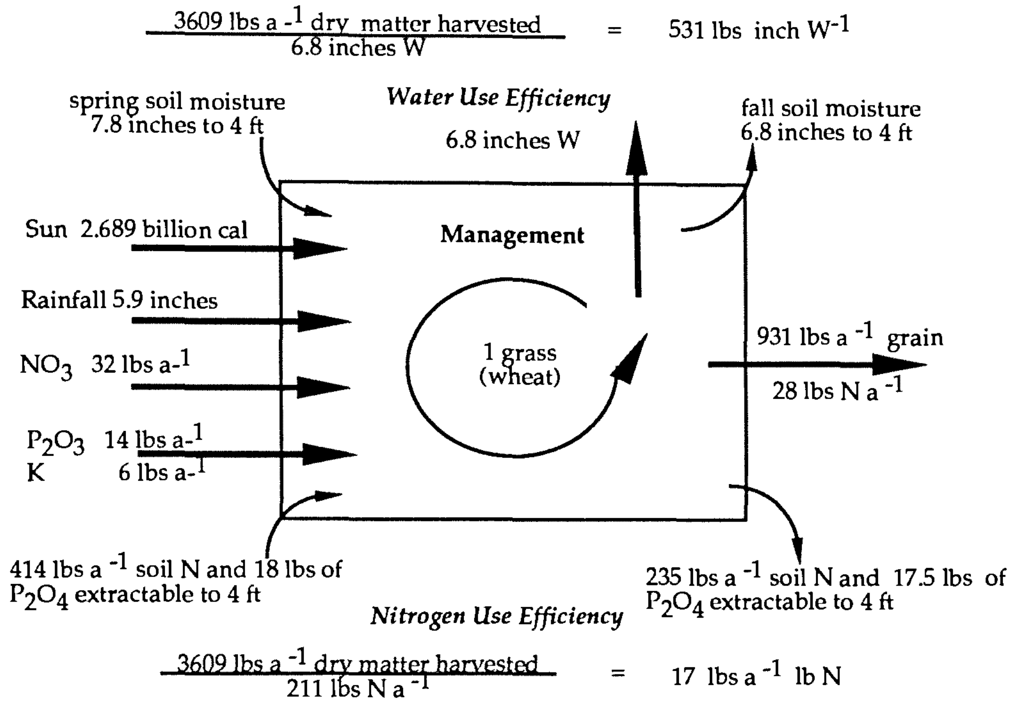


Figure 3.36. Gross inputs, outputs and efficiencies from the west no-till site during the summer of 1990. Spring soil samples were taken prior to the application of inputs and are not included in the 414 lbs N and 18 lbs P.

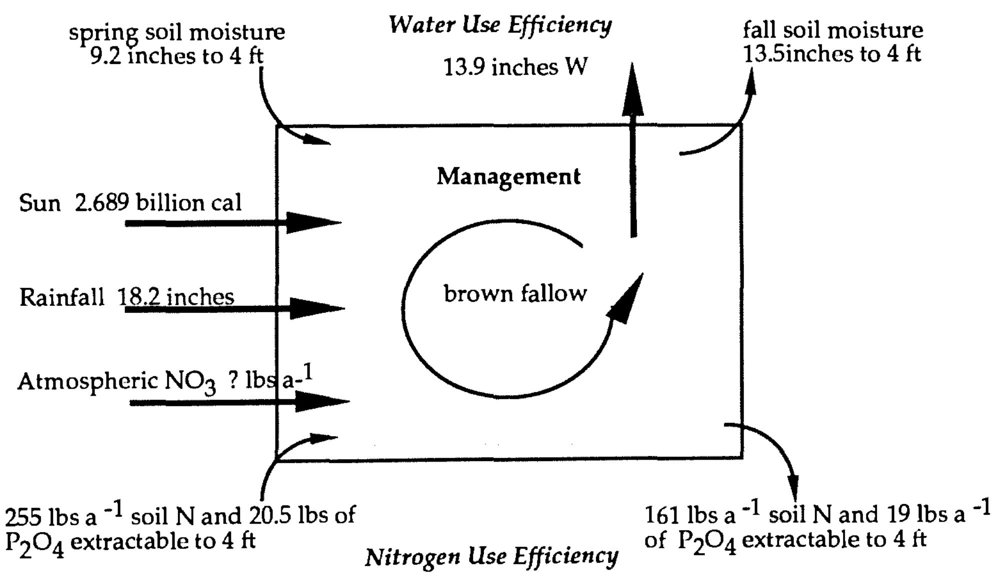


Figure 3.37. Gross inputs, outputs and efficiencies from the west no-till site during the summer of 1991.

WEST ORGANIC SITE

West mixed grass prairie ecosystem

Geologic and Social History

The west organic site in Hettinger County, part of the unglaciated Missouri Plateau of the Great Plains Province, traces it's geological history back to the Paleocene period of the Cenozoic era. The Sentinel Butte Formation was the upper most formation of the Fort Union Group. A darker color then the Tongue River Formation, this continental sediment was comprised of fine silt, medium-grained sandstone, carbonaceous and bentonitic claystone, and lignite. Thick beds of sandstone in the lower part of the Sentinel Butte Formation were important sources of ground water.

The topography, essentially shaped by running water, drained into an intermittent creek, Dayton, which discharged into the Cannonball River, which flowed into the Missouri and thence to the Gulf of Mexico. None of the upland surfaces drained by the Cannonball River were flat; at floodstage the river and creeks swung from one side of the valley to the other carving the intervening region into valley slopes. The river was named for the round sandstone concretions (mineral matter deposited in spherical masses) which resembled cannonballs; they were left behind when the softer silt and clay deposits were eroded away. Wind also formed the topography. Wind eroded depressions, blow-outs, resemble elongated prairie potholes lying in a northwest to southeast direction. They were formed 100,000 years ago (Trapp and Croft 1975, Bluemle 1977 and 1991, and Willard 1921). Ancient people, nomadic tribes, occupied the vicinity of the west organic site and left behind artifacts such as arrowheads, peace pipes, and boulder rings of undetermined function. Explorers, hunters, traders and cattlemen came. Hettinger County was part of the Nebraska Territory in 1854. The Northern Pacific Railroad divided up the unsettled, unsurveyed territory of Dakota Territory to give the appearance of settlement for the promotion of the sale of their bonds. Hettinger was part of Stark County from 1879 until 1907 when the final boundaries were set and a county government established.

Ranchers occupied the lands in the early years of Euro-American settlement. Ranchers on the Cannonball River were neighbors to ranchers on the Antelope Creek and the cattle grazed the open range.

In 1905 there was a great influx of settlers. Land barons such as William H Brown of Chicago enticed second and third generation Euro Americans to come to North Dakota with descriptions of black soil about 2 feet deep, clay subsoil and good running streams fed by springs. One promoter wrote in the January 1909 issue of the North Dakota Magazine, "I can raise anything here that I can raise in Wisconsin and more of it".. He went on to describe 10-20 bushel (bu) wheat on spring breaking. By 1909 there were 7000 inhabitants in Hettinger County (Bern 1977).

One of the cattle ranchers described this time in history, "From that period on, a gradual process of disintegration of what had once been a matchless cow country, took place. Using horse-drawn and large powered machinery, the luscious rich grasses of the prairie were turned under in an incredibly short space of time, transforming an otherwise rich, natural stock range into what, at the end of twenty years, proved to be semi-desert, where dust storms raged, blotting out the sun and where the drifting soil in many instances covered up fences. Black blizzards were infinitely more devastating than the white ones (Kolkema 1941)." Settlers had brought with them their humid-area ways of living to a land of recurring drought and flood (Kraenzel 1955).

The grandfather of the present owner of the west organic site (homesteaded in Hettinger County in 1905) came from Ohio with the second "boom" of growth in North Dakota. Historical accounts of wheat production in Hettinger County describe 1906 and 1909 as bumper crops, 1907, 1908 and 1912 as average, 1913 as drought and 1917 and 1918 as very dry, and 1919 was described as the year of the plague; the humans were overcome with Spanish flue and the wheat with Black Stem Rust (Bern 1977 and Kraenzel 1955). A graph of county averages for wheat production for

Hettinger County years 1920 to 1990 reflect the boom-bust cycle described by the historians (Figure 3.41).

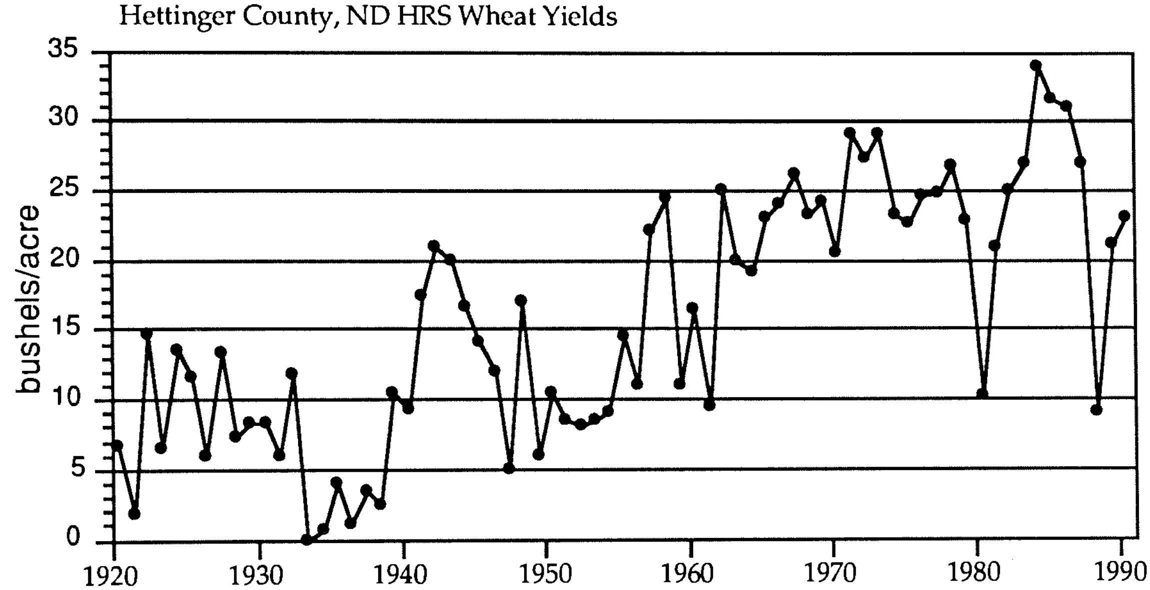


Figure 3.41. Hard red spring (HRS) wheat production in Hettinger County, North Dakota (North Dakota Ag. Statistics).

To hedge the drought and violent storm conditions of the Great Plains climate, grandfather raised cattle and grain. Father added sheep and hogs and the son, the present owner, farms in 20 rod strips, and grew 5 varieties of wheat each having different growth parameters. This farmer's account of the production years prior to this study were 1987-hailed out, 1988-dried out, and 1989-1/4 crop (wheat 12 bu).

Other crops grown on the farm were buckwheat, clover for plow-down, oats and barley for cash grain and livestock, alfalfa and hay. There was a reproductive herd of 102 Angus-herford cross on this farm. In 1991 there was an outbreak of Anthrax *(Bacilus anthracis)* in the county and this farmer lost 7 cows. Vaccination stopped the further spread of the disease on his farm. Sheep and hogs were discontinued in the 1970's.

Since homestead days, it has been traditional for several generations of this family to reside on this site. Presently there are four generations living in the two homes: mother, son, grandson and a one year old great grandson. Father had emphysema; with the advent of the chemical age it was the son's task to spread the commercial fertilizer and apply the herbicides. When his father died in 1976, the son decided to quit using these commercial inputs. He stated to the research team that after two years his veterinarian wondered why he was not required to make as many visits to doctor the farmer's cows as in previous years and after three years his personal doctor was amazed that he no longer heard the rasping in the farmer's lungs.

The farmer of the west organic site has been farming organically since 1976. In 1978 he began to ship his grain to an organic mill in Minnesota and has continued to market his small grains through this mill. The small grains were preconditioned at harvest and stored by variety on the farm. Identification by farm and variety unit follow the grain through the market process as required by the Organic Crop Improvement Association (OCIA). The farmer of the west organic site serves as an officer of this organization and on various other agricultural boards.

The sampling regime for the study of the west organic site consisted of an in-depth evaluation of a level one acre portion of a 62.4 acre field. Since this farmer owns adjoining sections of land, his fields were 20 rods wide and 2 miles long. His lands, classified as highly erodible lands (HEL) by

the USDA-SCS, required him to have a farm plan. This field scheme complied with the plan. The soil series on the farm closest to Sen, the reference soil, was Sham as verified by a soil scientist from the Soil Conservation Service of the USDA. It was a well drained slowly permeable soil formed in stratified alluvium (Table 3.41).

Soil Physical Characteristics

Measurements of the soil physical characteristics, bulk density, wet aggregate strength and dry aggregate size were taken from the west organic site in 1990 and 1991 (Table 3.41).

Table 3.41. Summary table of soil physical and chemical characteristics for the west organic site.

Nutrients

Nitrate mg kg^{-1}	0-3	3-6	6-12	12-24	24-48
'90 spring	9.73	11.43	11.75	7.83	4.82
fall	9.87	2.73	1.77	2.13	4.46
'91 spring	2.27	2.29	2.93	2.30	2.14
fall	2.62	1.32	0.41	0.41	0.45
Ammonium mg kg^{-1}					
'90 spring	4.01	5.28	2.70	3.76	3.52
fall	1.20	1.44	1.89	2.00	1.09
'91 spring	4.39	4.82	4.75	3.69	2.93
fall	3.03	2.33	2.03	2.08	1.88
Phosphorus mg kg^{-1}					
'90 spring	18.5	9.5			
fall	9.5	7.0			
'91 spring	19.0	6.0			
fall	17.0	8.5			

Soil Physical Characteristics

Horizon	Depth in.	Texture	Structure	Carbonates Effervescence	Roots	*Other features
A_p	0–6	loam.	md.SBK part to gran.	neutral	many	
B_{w1}	7-13	silt clay	md.SBK	neutral	common	
B_{w2}	13-23	clay	md.ABK	neutral	few fine	clay film, possible B_t
B_{w3}	24-29	clay loam	md.ABK	neutral	none	clay film, possible B_t, red mtles.
B_{k1}	30-38	sandy lay loam	massive	violent	none	red and gry mtles..
C	39-48	clay	massive	strong	none	

**Bulk Density	pH	Organic matter	Light F.mg kg^{-1}	TKN	N mg kg^{-1}
0.94g cm^3	7.5	2.40%	4075	1.01%	41
1.10g cm^3	7.4	3..82%	2515	0.63%	16

Aggregate Stability
80%
77%

Abbreviations defined:
*SBK = subangular or angular blocky;gran = granular; mtles = mottles; gry = gray; yl = yellow; br = brown; dk = dark; acc = accumulation; Fe = iron; md = medium; c = common; dst = distinct; thrds = threads.
**Bulk densities presume a particle density of 2.65 g cm^3; in soils with high rates of organic matter this assumption may be in error.

Even though the west organic site was disked, vibrashanked and seeded in 1991 before the wet aggregate sample was taken, the measurements for 1990 and 1991 were similar. Dry soil particle size category of less that 0.25 mm on this organic site were less than 17% in 1990 and 15% in 1991(Figure 3.42). Other tests conducted on this site were pH, organic matter, the lightfraction portion of organic matter, nitrogen (N) and phosphorus (P) (Table 3.41).

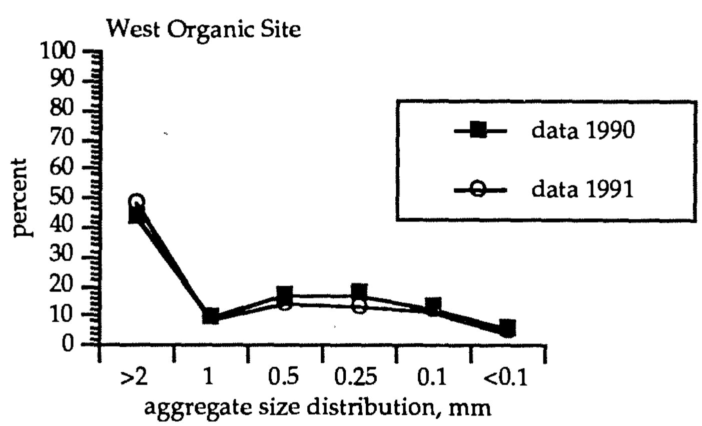


Figure 3.42. Soil aggregate size distribution for 1990 and 1991 oats acreage.

Soil Moisture

The amount of plant available soil moisture (Table 3.42) was an important factor in determining plant growth. Available soil water estimated by the North Dakota Extension Service (EXT SF 760, 1990) on November 14, 1988 was 0-2 inches and Nov. 6, 1989 was 2-4 inches. Rainfall events in this region were intense, of short duration and frequently contained hail. More than 75% of the annual precipitation occurred between April and September (SCS 1990).

For example, precipitation on the west organic site for 1990 was 10.83 inches (Table 3.42); records for May, June, and July of 1990 indicate 8.44 inches of the total precipitation occurred in those months. Of 12 rainfall events in June of 1990 yielding 3.74 inches of precipitation, 2.64 inches fell in 3 major events (Figure 3.43). Precipitation in 1991 was about the same as the previous year but there was 1/3 of the harvest. Confounding factors were grasshoppers, aphids, and a hail storm on July 20th. Observations of yellow patches of grain were also noted in areas of high populations of field bindweed *(Convolvulus arvensis)*.

Table 3.42. Total soil moisture at 0-48 inch sampling depth for spring and autumn of 1990 and 1991.

Soil Moisture

	0-3	3-6	6-12	12-24	24-48	total	precip	est W
'90 spring	0.47	0.68	1.30	2.76	5.61	10.83	10.07	14.7
fall	0.38	0.41	0.80	1.62	2.96	6.17		
'91 spring	0.24	0.33	0.96	2.04	3.14	6.71	10.57	8.8
fall	0.45	0.49	1.27	2.59	3.68	8.48		

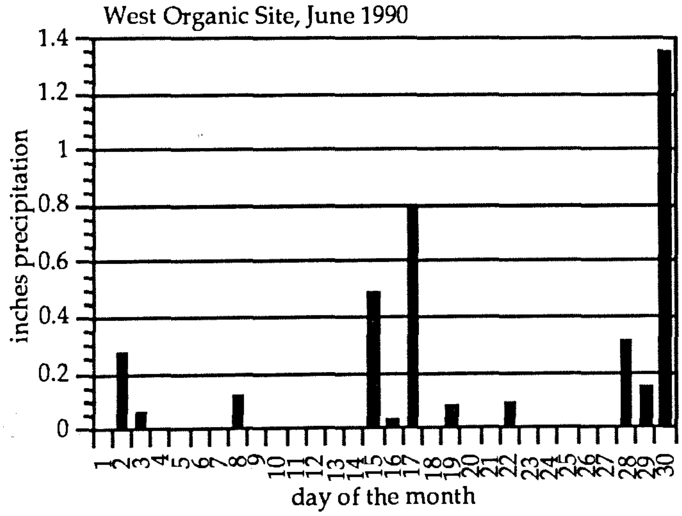


Figure 3.43. Rainfall events on the west integrated tillage site for June, 1990 (National Climatic Center). Rainfall on the Great Plains comes during violent thunderstorms.

Soil moisture was determined at this site by gravimetric sampling to a depth of 48 inches during the spring and autumn of 1990 and 1991 (Table 3.42). Precipitation estimates recorded at the nearest weather station during this period totaled 10.57 inches in 1991.

Nitrogen Dynamics

In this organic farm agroecosystem, N entered the soil through atmospheric precipitation, decomposition on organic matter and nitrogen fixation by leguminous crops such as clover and

alfalfa, and application of manure from his livestock operation. There were no industrial nitrogen inputs into this agroecosystem.

The N mineralization and immobilization transformation cycle was affected by factors such as the residual N remaining from the previous year, the amount, source, timing and method of application of the current year's infusion of N, the current year's response to climatic factors such as precipitation and temperature and the way in which all of these factors affected the biological system.

In an attempt to quantify the effects of these dynamics on soil fauna (bacteria, mites, and springtails) soil cores were extracted to a depth of 15 cm on eight separate days from June to September, 1990 (Figure 3.44). Peak microbe populations were measured in the first sampling dates, Julian day 160 (June 9) and 175 (June 24). There lowest numbers were measured Julian day 250 (September 7). Springtail populations peaked on Julian day 220 (August 8) and again on Julian day 250 . The lowest point was the beginning of July (Julian day 190). Mite populations peaked on the first week of July (Julian day 190) and again the first week of October (Julian day 280). The lowest measurements were taken on the last week of June (Julian day 175) and the first week of September (Julian day 250). All of the tillage practices in 1990 were conducted prior to population sampling. The observed rainfall events do not to correlate with the rise and fall of these populations.

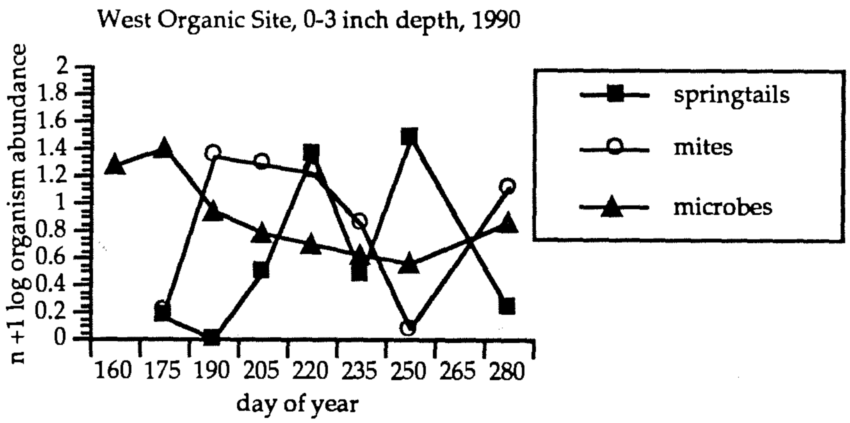


Figure 3.44. Soil fauna population measurements at one soil depth and eight sample dates for 1990. Abundance springtails and mites = 1000 =g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

In 1991 there were 9 sample dates (Figure 3.45); one earlier and one later than the 1990 sampling period. The greatest variability for the populations occurred between Julian days 175 and 235 (August 24). This was after the spring field operations were completed, the heavy rains of June were past, and before harvest was begun.

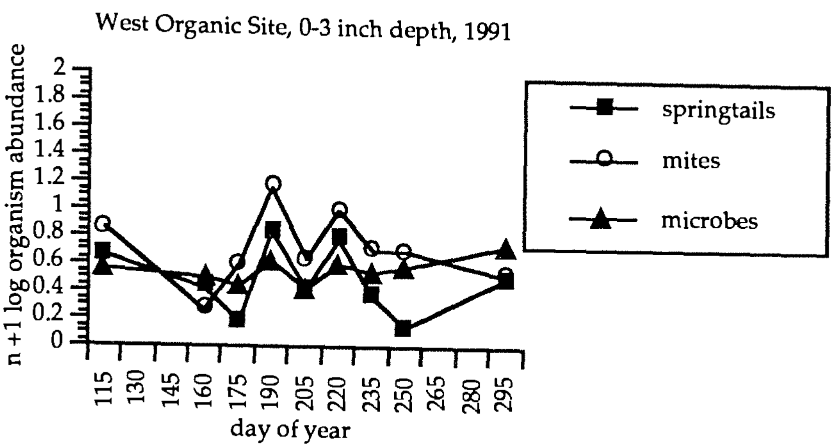


Figure 3.45. Soil fauna population measurements at one soil depth and nine sample dates for 1991. Abundance springtails and mites = 1000 =g dw soil; abundance microbes = mg kg^{-1} ammonium for 1 g dw soil.

In addition to microarthropods, other arthropods were quantified to obtain a better understanding of the biodiversity on the site. Some arthropods were considered economically important with regard to crop loss; the ecological importance of arthropods to agriculture in not well documented.

Pitfall traps were collected on 7 successive sample dates for 1990 and 1991 (Figure 3.46). The predominant arthropods collected from the west organic site were as follows: spiders (7 families), beetles (17 families), flies (11 families), true bugs (3 families), hoppers (2 families), bees (9 families), moths (3 families), grasshoppers and crickets.

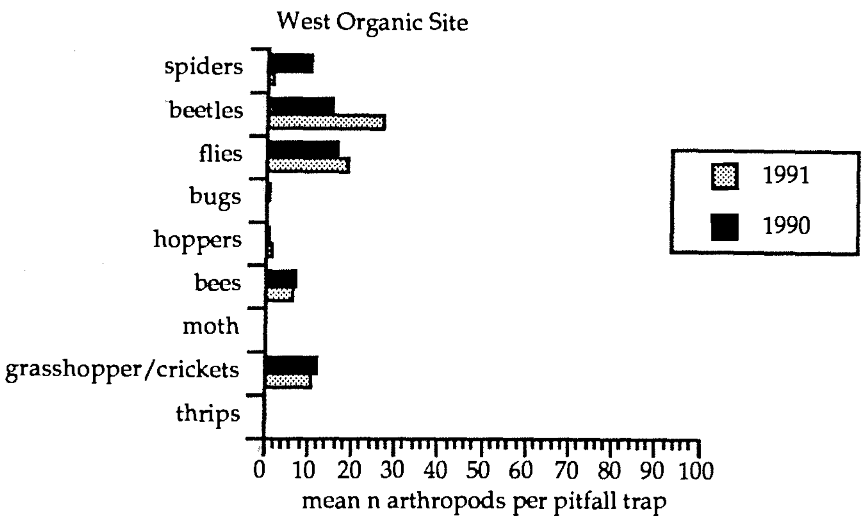


Figure 3.46. Arthropods collected in pitfall traps on 7 sample dates in 1990 and 1991. Amounts indicate the average number of arthropods per trap for the total sampling period. Sample size = 12 oz cup set at soil level for 4 consecutive days.

The predominant families of arthropods trapped in 1990 were as follows: daddy long legs *(Phalangida)*, ground beetles *Carabidae)*, long-legged flies *(Dolichopodidae)*, buffalo gnat *(Simuliidae)*, and common sawfly *(Tenthredinidae)*. Of the comparison of grasshoppers and crickets, it was mostly crickets that came to the pitfall trap in both 1990 and 1991. The predominant families in 1991 were wolf spider *(Lycosidae)*, ground beetle, short-winged mold beetle *(Pselaphe)*, and carrion beetle *(Silphidae)*, bee fly *(Bombyliidae)*, gall midge *(Cecidomyiidae)*, and a parasite of flies and beetles *(Chalcididae)*.

The Margalef index is an index of diversity. In this study it was used to measure the diversity of insect families of predators and herbivores occurring on the west organic site. The higher the number the higher the diversity and this agroecosystem shows a consistent high level of diversity through time and between years. No pest out breaks were observed.

Table 3.43. The Margalef index of pitfall trapped insects for six sample dates and two years collection of predators and herbivores from the west organic site.

Margalef Index of Pitfall Trap Insects

West no-till	Predators						Herbivores					
Day of year	160	175	190	205	220	235	160	175	190	205	220	235
year 1990	3.53	5.28	6.04	5.42	5.32	4.70	1.88	0.96	2.16	0.66	1.04	1.36
1991	5.78	5.40	4.12	5.74	5.68	5.40	1.22	1.32	0.88	2.12	1.68	2.24
mean	4.66	5.34	5.08	5.58	5.50	5.05	1.55	1.14	1.52	1.39	1.36	1.80

Plant Species Present

The vegetation present (complete list Table 3.44) on the west organic site consisted of annual and perennial weeds and crop. The typical rotation on this site was wheat *(Triticum aestivum)* / corn *(Zea mays)* / clover-fallow *(Trifolium pratense)*; however for management reasons in 1990 and 1991 oats *(Avena sativa 'Otana')* was produced.

With the exception of wild buckwheat *(Polygonum convolvulus)* and kochia *(Kochia scoparia)* observed in 1990, the weed species were the same for both years of observation They were as follows: field bindweed *(Convolvulus arvensis)*, green foxtail *(Setaria virdis)*, and red root pigweed *(Amaranthus retroflexus)*. The field bindweed was found in 5 foot diameter patches at the rate of 2-3 patches per acre. Green foxtail density in 1990 was 4.2 plants sq ft $^{-1}$ and in 1991 the season average was 1.37 plants sq ft $^{-1}$. Red root pigweed was observed at a density of 1 plant sq ft $^{-1}$ in August of 1990 but only one observation was made in early 1991. The underseeding of sweet clover in 1991 resulted in an average density of 2.08 plants sq ft $^{-1}$.

Table 3.44. Plants present in the west organic agroecosystem.

West Organic System Species			
Avena sativa 'Otana'	*Amaranthus retroflexus*	*Convolvulus arvensis*	*Kochia scoparia*
Trifolium pratense	*Descurainia sophis*	*Polygonum convolvulus*	*Setaria virdis*

Management

The objective of an organic farm management system is to use natural soil-building routines and crop rotation schemes instead of synthetic inputs to supply nutrients and to control weeds, insects, and disease in the production of agronomic crops and livestock (Kirschenmann 1988). Typically a clover-fallow was included in the rotation on the west organic site every third year. Prior to this study the rotation on the west organic site was wheat/corn/clover-fallow. In 1990 there was a very high market demand for organic oats. This farmer wanted some fertile clean acreage for his oats production in 1990 so he changed his rotation.

Seedbed preparation includes waiting until the soil temperatures increase enough to produce the first flush of weeds (about May10). He then cultivates his field with a vibrashank and again the third week of May; within a half day of the second working he drilled in his untreated Otana oats at the rate of 3 bu a $^{-1}$. There were no tillage operations after harvest.

The spring of 1991 the soil temperatures remained very cold, 34.9°F for the first seven days of May; the weed seeds and volunteer grain didn't germinate. The farmer reported that it was not his usual practice to continuous crop but he felt he had no choice when considerable volunteer grain was expected to sprout. In 1991 he disked this site the first week of May and the third week

of May he worked the field with the vibrashank; within in one-half day he seeded untreated Otana oats at the rate of 3 bu a^{-1}. There were no other tillage operations on this site in 1991.

Production and Resource Use Efficiency

The 1990 crop of oats was swathed on August 5th and combined August 12th. Net primary production (NPP) was 10,691 lbs a^{-1} with 4317 lbs a^{-1} marketable grain (farmer field estimate 67.3 bu a^{-1}). The straw was harvested down to 7.5 inches for livestock feed and bedding. Nitrogen removed with the 1990 grain and straw was 139 lbs a^{-1}.

The 1991 oats crop received hail damage on July 20; grasshopper and aphid problems were also observed. The crop was swathed August 19 and combined August 24. NPP was 3525 lbs a^{-1} with 873 lbs a^{-1} marketable grain (farmer field estimate 10.7 bu a^{-1}). The straw was harvested down to 4.5 inches; N removed with the 1991 grain and straw 27 lbs a^{-1} . Using preseason and post-season soil samples taken to a 48 inch depth, total gravimetric water, nitrate and ammonium content were determined mathematically. Using these factors plus locally recorded precipitation amounts and an undetermined amount of atmospheric nitrogen plus nitrogen inputs, gross nitrogen and water use efficiencies were calculated (Figures 3.47 and 3.48).

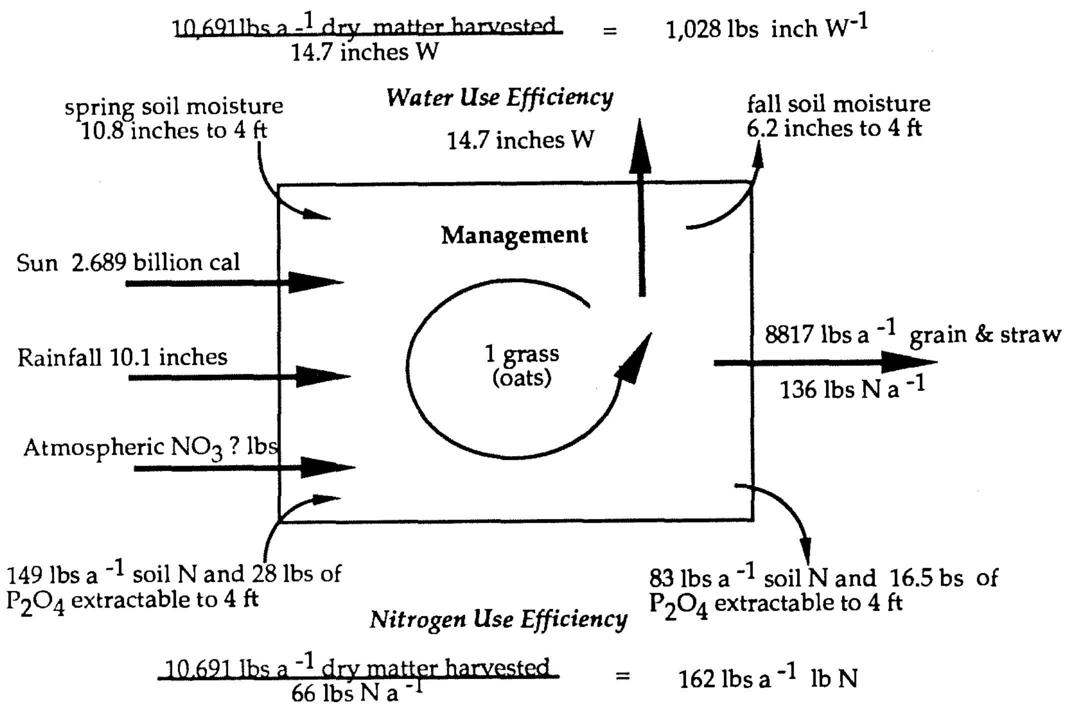


Figure 3.47. Gross inputs, outputs, and efficiencies from the west organic site during the summer of 1990.

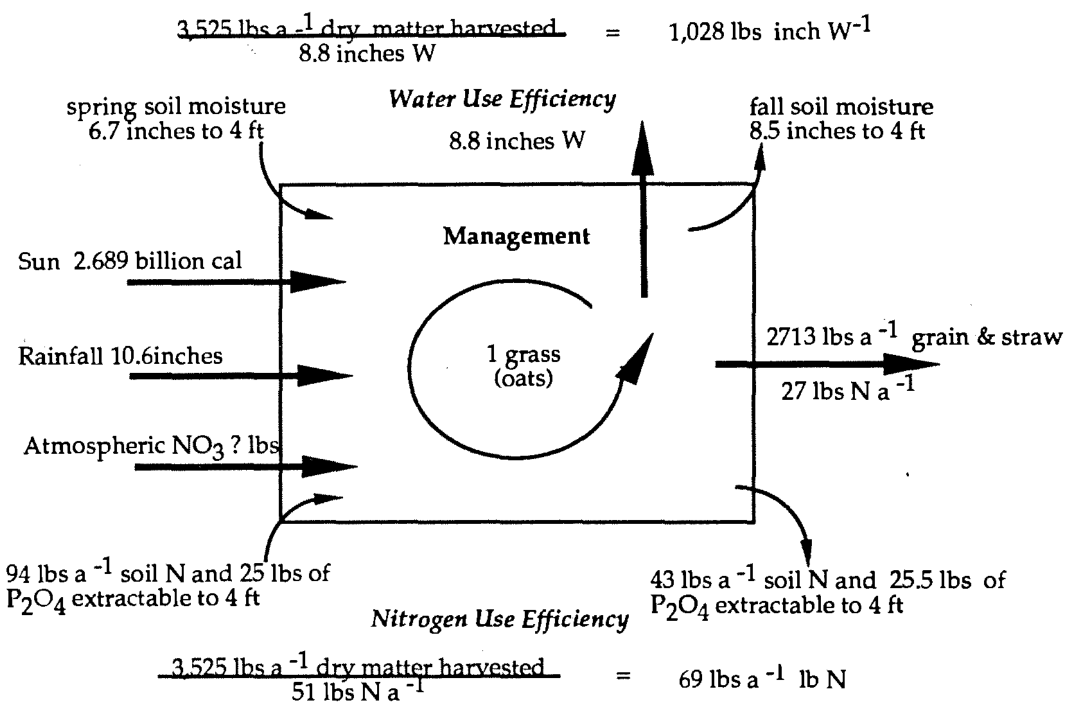


Figure 3.48. Gross inputs, outputs, and efficiencies from the west organic site during the summer of 1991.

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