United States
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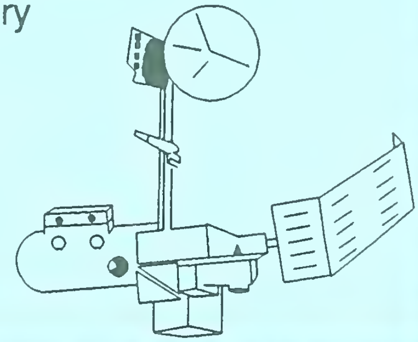
ARS-89

June 1991

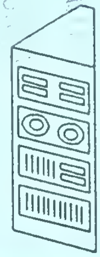
Sustainable Agriculture for the Great Plains, Symposium Proceedings

Fort Collins, Colorado
January 19-20, 1989

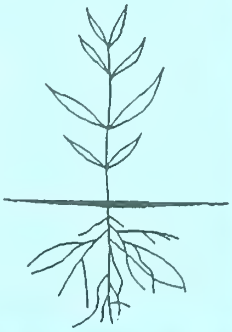
Remote Sensing
Image Analysis
Aerial Photography
Radiometry



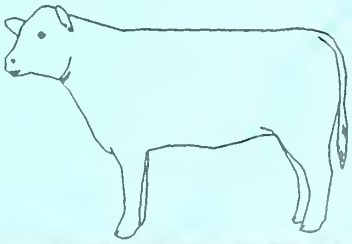
Computer Simulation
Mathematical Modeling
Data Analysis
Decision Support Systems
Image Processing
GIS



Plant Ecology
Plant Physiology
Range Management
Climate Change
Regional Monitoring
Soils and Hydrology



Grazing Management
Beef Production
Global Warming
Plant/Animal Interface
Grazing Behavior



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Edited by:
Jon D. Hanson
Marvin J. Shaffer
Dan A. Ball
C. Vern Cole

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Table of Contents

Preface

The Great Plains Systems Research Unit, Fort Collins, Colorado hosted a symposium entitled "Towards a Sustainable Agriculture for the Great Plains" January 19-20, 1989. Our goals for the symposium were to explore opportunities for joint projects and to develop a network for collaboration among federal and state scientists of the Great Plains.

During the symposium, participants

- presented problems and challenges from a regional perspective,
- presented conceptual frameworks for describing and analyzing agroecosystems,
- described methodologies suitable for regional analyses,
- identified and described natural resource data bases,
- determined research requirements for development of sustainable agricultural systems for rangelands and croplands, and
- discussed both institutional and 'grassroots' mechanisms for establishing a regional network of scientists.

The papers included in this volume represent the results of the symposium and have undergone anonymous peer review. We would like to express our thanks to those who served as peer reviewers. Moderators for the technical sessions were: Jan van Schilfgaarde, USDA-ARS, Fort Collins, Colorado; Lee Sommers, Colorado State University, Fort Collins, Colorado; and Ron Follett, USDA-ARS, Fort Collins, Colorado.

Chapters 1-13 are invited papers and the remaining chapters are from volunteer papers presented during the poster session.

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PROGRAM

Thursday, January 19, 1:00-9:00 p.m. (Chairman, Jan van Schilfgaarde)

Symposium Objectives	Jan van Schilfgaarde
Regional Perspectives and Challenges for Research	James Welsh
Regenerative Agriculture	Robert Rodale
A Conceptual Framework for Regional Analysis	John Stewart
New Directions in Soil Management Research	Albert Black and Armand Bauer

Poster Session

Friday, January 20, Morning Session (Chairman, Lee Sommers)

Driving Variables Controlling Soil and Plant Processes	Marvin Shaffer
Soils as a Driving Variable	Klaus Flach
Integrating Wildlife into Great Plains Agriculture	Del Benson
Management as a Driving Variable	Gary Peterson
Economics as a Driving Variable	Melvin Skold
Common Sense and Statistics	Mike Brown
Simulation Modeling for Hypothesis Testing	Jon Hanson

Afternoon Session (Chairman, Ron Follett)

Remotely Sensed Data	Ray Jackson
Geographic Information Systems	Joe Berry
Linking Resource Data into Modeling Programs	Allan Jones
Soils Data Bases for the Great Plains	David Anderson

Discussion

A Research Network for the Great Plains: I.	Bobby Stewart
A Research Network for the Great Plains: II.	Vernon Cole

Discussion

Forward: Towards a Sustainable Agriculture for the Great Plains

Jan van Schilfgaarde. Associate Area Director, Northern Plains Area, Agricultural Research Service, Fort Collins, Colorado.

van Schilfgaarde, J. 1991. Towards a sustainable agriculture for the Great Plains. Pages 1-4 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

This symposium was organized by the scientists of the Great Plains Systems Research Unit, ARS, in honor of Albert R. Grable. In his distinguished career. Dr. Grable made exemplary contributions to the development of two formal plans for a national program of research in the Agricultural Research Service, known as MAPS and the Strategic Plan: in fact, without him, neither plan would have seen the light of day. More to the point, however, he had a major hand in sanitizing, directing, and initiating research programs in soil productivity, in farming systems and in remote sensing for agriculture. The last three years, he organized and directed the Great Plains Systems Research Unit in Fort Collins. Thus, it is appropriate that we take a look at where we are in Great Plains Farming Systems and where we need to be going.

Before addressing the objectives of this symposium specifically, let me explain what the symposium is *not* intended to be. A number of serious issues confront American agriculture. They include economic viability, resource conservation, environmental quality, and long-term sustainability. These terms mean different things to different people; thus some of you may have expectations that differ greatly from others', or from the organizers'. Let us briefly consider some of these issues.

The 1985 Farm Security Act and the last two appropriation bills made clear the interest of Congress in what has since been dubbed LISA—Low Input Sustainable Agriculture. LISA is seen by some—incorrectly—as simply an attempt at reducing farm input costs to increase profitability. Others see it as a euphemism for organic farming. I see it as a concern that heavy dependence on ever increasing amounts of purchased inputs is not only threatening the economic viability of many farms, but also their continued natural productivity and the environment they impact. It is gratifying to note the strong interest among farmers and academicians in LISA, though the enthusiasm in some quarters of USDA is, at best, muted. Important as it may be, LISA is *not* on the agenda today.

A parallel concern deals with water quality. As you know, the research community has rallied behind it as a top priority topic. Water quality is closely linked with LISA in that groundwater quality degradation through agricultural practices is frequently associated with high levels of purchased inputs. Water quality has become of concern especially in the Midwest and the East where fertilizer nitrogen and nematocides often have been found in drinking water, but also in the irrigated West. To the age-old problem of salinity in irrigation drainage has now been added the disturbing presence of trace elements, sometimes at biologically harmful levels. In some circles, the finding of selenium in California's Kesterson reservoir has raised the question whether irrigation agriculture can be sustained without undue harm to the environment (van Schilfgaarde 1988). The Great Plains don't escape either, considering the explosion of irrigation in the Sandhills of Nebraska. Apart from the potential of water pollution, Skold and Young (1987) concluded that much of the pivot irrigation in Nebraska would not be economically viable except for government subsidies. Might it be that irrigated corn production in the Sandhills is not sustainable because of groundwater mining *and* water quality degradation *and* economic viability?

Another issue, of great concern to some, is the industrialization of American agriculture at the expense of the family farm. It has been explained to me—by erudite and knowledgeable experts like Vern Ruttan—that the trend to ever larger farm units at the expense of medium size, owner-operated farms is inevitable, presumably the consequence of natural laws enunciated by economists. It is associated, of course, with specialization (generally monoculture), high capitalization and high levels of purchased inputs and the alleged economies of size. A recent book by Strange (1988) provides convincing arguments to demonstrate the fallacy of some of those assumptions. It is true that man-made laws—especially government policies—favor the large, corporate farm. It is true that, especially before 1986, the tax laws penalized the smaller operator in favor of the large concern. However, it seems that the larger, specialized farming units are financially less robust and, pertinent to today's discussion, are more likely to insult the environment. In short, large industrial farms are not necessarily more efficient, while smaller owner-operators are likely to be better stewards of the land.

This last expression—stewards of the land—is what ties together the interest in LISA, the concern with water quality and the issue of family farms. It also reminds one of conservation practices and erosion control, and of government programs to provide inducements for reduction in erosion. Since 1985, the key phrases are cross compliance and conservation reserve. Are these programs effective; are they needed; do they suffice? The concept "stewardship" leads us back to "sustainability".

The word "sustainable" in the symposium's title has various connotations. Bob Rodale (1988) probably prefers regenerative; some use alternative; others, conservative. The objective implied here is effective and productive use of natural resources so that they are not diminished, but conserved or even enhanced—to coax the soil into an abundant harvest, rather than force a crop in spite of nature. Put negatively, we need to know whether and where, because of short-term economic gain or ill-advised policies, we mismanage our resources.

This brings me to farm production systems, systems engineering and systems research. The scientific method, the guiding light in the 19th and 20th centuries, has been dominated by analytical thinking: the reduction of the whole into its parts in order to evaluate the parts one at a time. But a farm is an organic whole—an organism—and not just the sum of its parts. As we change one thing, we affect many others. Thus to understand the whole, we must synthesize after we analyze. Rawlins (1988) gives a useful synopsis of how, through systems science, we can systematically synthesize the system from its parts. Such synthesis may be described as integration over function, over space, and over time.

Conceptually, there isn't much new in systems science. The competent researcher has always had a model in mind with which he assessed the significance of his data. What is new is that we now have the tools to handle, to manipulate and to "remember" many more interactions, larger data bases and very complex systems. Simulation models, geographic information systems, expert systems, and related tools now permit us to test hypotheses, evaluate the adequacy of our data bases, conduct sensitivity analysis and, with considerable trepidation—or callousness, as the case may be—make predictions. Parenthetically, it should be noted that it is not necessary for models to make good, long-term predictions for them to be useful in affecting management decisions (Clark 1986).

This then, is the essence of the mission of the Great Plains Systems Research Unit, and forms the basis for this symposium. We wish to use existing data bases, and generate new information, to develop models that explain the workings of various systems and subsystems pertinent to resource utilization in the Plains for agricultural production. We wish to use these models, not so much to make predictions, but to guide us in making management decisions, or management recommendations. We recognize that this requires the cooperation of geneticists, physiologists, soil scientists, and others in the historic sense, but that it requires a bit more. It requires a willingness and an ability to communicate with those in other disciplines than our own. And it requires a formal structure, a system, and thus the skills to build such a structure. It truly requires inputs from a wide range of disciples, from ecology to engineering.

The Plains form a unique and wondrous ecosystem. Harsh, yet productive. Slow, but inexorable in its rate of change. Unpredictable except in its changeability. Because of its harsh climate, because of the generally low precipitation, damage done to its soils or its vegetation tends to be slow to heal. The balance between regeneration and deterioration, between economic production and heartbreaking failure is precarious and subtle. What happens in the Plains is of importance to those who live and work there, and to those who don't.

Today and tomorrow, we shall have the privilege to listen to a wide range of experts, from generalists to specialists, from nearby and from far away, who will lead us in thinking through what it takes to evaluate the pertinence of management practices, or farming systems, in the Great Plains.

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Regional Perspectives and Challenges for Research

James R. Welsh, Dean and Director, Agricultural Experiment Station, Montana State University, Bozeman, Montana.

Welsh, James R. 1991. Regional perspectives and challenges for research. Pages 5-8 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

The object of this paper will be to provide a brief overview of the Great Plains characteristics and requirements regarding a sustainable agriculture. In my view, a more appropriate title would be "A Sustainable Society for the Great Plains" since societal and agricultural problems are inextricably linked. Any attempt to address Great Plains issues without considering societal impacts would be inappropriate at best and disastrous at worst.

The Great Plains have been described countless times in many different ways. One of the first obvious characteristics is size and distance. The ten states comprising the Great Plains represent approximate 1.5 million square miles, or about 900 million acres. The physical environment is wildly diverse. Dramatic extremes in elevation, temperature, precipitation, evaporation and wind direction and velocity contribute to a highly variable and stressful environment. Montana provides an excellent example of environmental variation. The state has experienced moderate to severe drought in seven of the last nine years, yet agricultural production levels have ranged from the poorest to the best on record.

Great Plain's agricultural production is relatively limited in diversity. Cattle, sheep, hogs, corn, sorghum, cotton, wheat and barley encompass an overwhelming majority of the agricultural production value in the Great Plains. Because of the relative lack of species diversity, the Great Plains can truly be represented as an extension of a limited set of mono-culture systems.

Societal configuration in the Great Plains is characterized as being concentrated, basically, in small communities with a relatively few large population centers. The culture is primarily agrarian and individuals are either directly involved in agricultural enterprises or are no more than one or two generations removed from such activity. The people are fiercely independent and strongly prefer to "work for themselves" rather than becoming part of a larger organized structure. Livestock producers, in particular, place high value on their independence. The population has an extremely strong work ethic. Employers from around the country traditionally look to the Great Plains as an excellent source of individuals to add to their work force. The society is currently undergoing an intense transition as a reflection of recent financial stress and subsequent restructuring of individual production units and rural communities.

A few comments on the current condition of the Great Plains are in order. Montana-developed information will be used for illustration purposes with the assumption that it likely represents a majority of the Great Plains rural areas. The Annual Montana Farm and Range Survey will be used as a database. This survey is conducted annually by sampling approximately 1,200 farm and ranch operators for their opinions regarding various aspects of agriculture and rural community conditions. A copy of the 1988 summary is attached. Increased moisture and improved prices ushered 1988 in as a year of optimism; however, the year subsequently proved to be one of the driest years on record. The 1988 survey showed that Montana's farmers and ranchers were much less concerned about the financial condition of Montana agriculture in the beginning of 1988 than they were at a comparable time in 1987.

Some minor signals emerged that some farm and ranch operators anticipated expanding their operations over the next five years. The survey respondents indicated that over half of them would likely choose farming/ranching as an occupation if they had it to do over again, yet approximately half of the respondents indicated that they would likely discourage young people from taking up farming or ranching. Quality of community life evolved as a major concern. Many respondents indicated that indicators such as time neighbors spent visiting, community closeness, willingness of people to volunteer for community projects, willingness of people to run for public office, and overall quality of life in the community had significantly decreased. Likewise, respondents indicated that the quality of community services appeared to be deteriorating. Such categories as law enforcement, county government, roads and bridges and availability of consumer goods were often rated as fair or poor. A most striking signal, however, was the evaluation of employment opportunities in which 77% of the respondents indicated poor opportunity and only 4% indicated good to excellent opportunity.

If these data are representative of the Great Plains, the signal is strong that the rural fabric is deteriorating significantly. There are apparently few jobs, services are reduced, the economy is poor and community spirit is deteriorating. On the other hand, most of the operators surveyed intend to keep on farming at least for the short run and, in some cases, intended to expand.

What do the people want from their public resources? How should we program our activities to respond to the above described current conditions in the rural Great Plains? As an initial step, I believe we must dialog more directly with the people to determine their priorities and match those with our own research activities. In December, 1988, a series of nine Town Hall Meetings were conducted around Montana to solicit input from decision makers, clientele and others regarding concerns and issues which could appropriately be addressed by Montana State University, the Extension Service and the Agricultural Experiment Station. A report of these meetings is attached. While some very specific issues such as water, weed control and alternate crops were identified, the underlying theme throughout the entire nine meetings centered around improved economic opportunities and the need for better information affecting rural community development. The public is clearly looking to their public education, information and research programs to provide the much needed databases to revitalize the rural Great Plains.

Given the above information, what possible strategies could be used to address the Great Plains' problems? First, it is clear that we, as program managers, need to do a better job of planning. We must position ourselves to address issues in the next 10-20 years as we deal with critical economic and cultural concerns. The Strategic Planning process could well be adapted to most of our program development. However, any strategic plan should encompass a broad spectrum of interests in order that we take into account a more holistic approach to Great Plains' problems. The MSU College of Agriculture, Experiment Station and Extension Service are nearing completion of a Strategic Planning process which identifies a series of goals for action-oriented consideration. Major goals include state leadership through image enhancement, economic development, organizational unity, improved academic base, increased funding, program priority and quality emphasis, faculty recruitment and development and recruiting and retaining high-quality students. With the identification of specific goals, a plan of execution with an appropriate timetable for each goal is being finalized.

The Cooperative Extension Service has recently adopted a new programmatic approach to many issues vital to the Great Plains. They have chosen to utilize issues and teams, rather than relying entirely on the more traditional compartmentalized or individual specialist method. The issues identified include alternative agricultural opportunities, building human capital, competitiveness and profitability in agriculture, conservation and management of natural resources, family and economic well being, improved nutrition, diet and health, revitalizing rural America and water quality. Flexibility and the ability to move personnel and resources toward issues of high priority in the individual states will be a key to the success of the issues approach to programming. However, Extension could well play a strong leadership role in bringing research and education together in a compatible fashion to solve Great Plains' problems.

Finally, several examples currently exist in which new approaches and ideas are utilized in problem solving. The holistic approach is receiving increased attention. This method looks at a problem or decision-making process in a global fashion.

Holistic methods can be applied to College teaching programs, natural resource management activities and administrative program development. In my opinion, it would be wise for us all to give more attention to the holistic approach.

On another front, low-input or sustainable agriculture, the theme of this Conference, is finally receiving the attention it deserves. In Montana, our very traditional agriculturalists are asking us for new methods of reducing input costs, protecting the environment and managing natural resources in a more desirable fashion. Very little emphasis is being placed on absolute yield increases.

Much greater emphasis is being placed on interagency team development. We are seeing new liaisons between the Agricultural Experiment Stations, the Extension Service, the Agricultural Research Service, the State Departments of Agriculture, the Soil Conservation Service and many other groups and agencies in addressing the vital questions of community development in the rural Great Plains. This is an area that should receive increased emphasis in order to capitalize on limited resources and address the true needs of the people.

New relationships are being developed with industry. Many public institutions, research agencies and other are revisiting the question of industrial relationships in order to maximize technology transfer. This is an area that should be investigated and nurtured carefully. Although numerous pitfalls exist, in general, industry/public institution relationships have proven to be extremely beneficial for society.

As a footnote, we should give more serious consideration to regionalization of our research, teaching and Extension programs. The research communities, in particular, have adopted this philosophy through regional research projects, regional approaches by USDA-ARS and other regionally-oriented activities. However, the Western Region has initiated a project to investigate potential regionalization of several programs being carried out by the teaching, research, Extension and international components. Again, the major motive is to provide the best information to the people on a least cost or most efficient basis.

In summary, the development of appropriate activities for the research community in sustainable agriculture, as well as all other aspects of Great Plains' production and society, must first take into account the needs of the people through appropriate dialog and evaluation. Strategic plans must be developed carefully utilizing interagency and industrial relationships wherever appropriate. The holistic approach should be carefully evaluated and used wherever possible. Finally, we must more carefully evaluate the potential impacts of our programs on the people of the Great Plains.

Agricultural Systems: The Importance of Sustainability

Robert Rodale[1], President of the Regenerative Agriculture Association and Chairman and Owner of The Rodale Press, Emmaus, Pennsylvania.[2]

Rodale, R. 1991. Agricultural systems: The importance of sustainability. Pages 9-16 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.). *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

Sustainability of agricultural production systems is rapidly becoming a major concern of agricultural researchers and makers of farm policy. That's a recent phenomenon. Until a few years ago. farm production was the major concern. Sustainability was never mentioned. It simply wasn't something people worried about.

Why the change? I see seven specific reasons for the rise of sustainability to a high place on the farm policy agenda.

The first is that right now there is enough food in the world. Surpluses are more of a problem than shortages. True, distribution of food in the world is uneven. Many people are going hungry. But the fault can hardly be placed at the feet of producers. They are literally creating mountains of food, much of it to be placed in long-term storage.

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[1] Deceased.

[2] Note: This article has been reprinted with permission from the *National Form*, Phi Kappa Phi Journal, Summer 1988. Pages 2-6.

That condition will almost certainly change in the future. But right now, thinkers about agriculture and makers of policy have a window of opportunity to ask questions about the future. They are wondering, Can we keep this up? Are the current high levels of production sustainable?

The second reason is that nonrenewable resources are vitally import to the operation of the conventional American system of agriculture. Without adequate and low-cost supplies of oil, gas, phosphate rock, and a few other similar resources, our agriculture would not be able to turn out large amounts of low-cost food and fiber. At the very least, there are likely to be erratic shifts in the price and supply of those inputs. This situation makes long-term planning difficult, and it creates worries.

Third, the high levels of production today are taking a toll on the farm environment. Soil erosion, degradation, and deforestation are widespread. That's particularly true in the Third World. Many millions of people are trading soil for food. You can see that happening on all continents, and even here in the United States, where much attention is given to soil conservation methods.

Escalation of pollution problems traced to agriculture are a fourth reason why sustainability is a major concern today. Increasingly, residues of fertilizers and pesticides flow into surface and underground water supplies. They also contaminate some foods and create air pollution. There is now a high probability that current agricultural methods will have to be changed to avoid unacceptable environmental damage. How, then, will production be sustained?

Fifth, world population continues to grow, in some places very rapidly. Although there is enough food now in total, what about five, ten, or fifteen years from now, when there will be a much larger number of mouths to feed? We can meet the challenge of feeding additional numbers by fully developing the unused internal resources of our farms and continually making our resource base better. Some ways to do that include developing new crops that are better adapted to local soils and climatic conditions and finding new uses for indigenous plants. Promising research is now underway on perennial grains, drought-tolerant crops like amaranth, and other, more resource-efficient crops that also provide a high level of nutrition.

Sixth, society will probably need agricultural production for energy and chemical feedstocks as well as food. So as fossil fuel reserves become more expensive, agriculture may have to bear a heavy additional burden. Can production be sustained given that requirement?

Finally, there's the family farm question. The role of personalized agriculture is a central theme in the culture and spirit of countries. Even if we are able to produce enough food and fiber on large, industrialized farms, can we sustain the idea of the good life in rural areas without a vibrant family farm sector? That question is a powerful motivating force in the current push in the United States for more-sustainable agricultural methods.

Given those seven concerns about current agricultural methods, where do we begin thinking about changes that could lead to sustainability?

I believe the best way to start is to look at the history of agriculture itself. We should ask how we got where we are today. After all, people have been eating for millions of years. And agriculture—the systematic production of food—is far older than manufacturing. It probably predates commerce itself. How come, after all these centuries, we seem suddenly faced with a crisis of sustainability?

For most of human history, people simply hunted and gathered food. They didn't do much, if anything, to interfere with natural processes. Living off the land and out of the bounty of the waters was the order of the day.

About 10,000 years ago, agriculture began. What can we learn about sustainability by looking back at what happened during those 100 centuries?

The most important lesson is that for the first 9,900 years of agriculture, farmers used a fundamentally different set of methods than they did during the most recent 100 years. For those first 99 centuries, farmers produced using nothing more than the internal resources of their farms, themselves, and their families. There were no inputs in the modern sense. Farming was not industrialized, in other words. Outside inputs such as tractor fuel, pesticides, and manufactured or mined fertilizers simply weren't part of the method.

The following chart illustrates that important point: it presents all the resources needed for agricultural production. Internal resources are listed in the left column; external inputs are in the right column. Down the middle is a line separating the two columns.

RESOURCE SYSTEMS FOR AGRICULTURAL PRODUCTION

INTERNAL	*EXTERNAL*
SOIL	HYDROPONIC MEDIUM
SUN—main source of energy	SUN—energy used as "catalyst" for conversion of fossil energy
WATER—mainly rain and small irrigation schemes	WATER—increased use of large dams and centralized water-distribution systems
NITROGEN—collected from air and recycled	NITROGEN—primarily from synthetic fertilizer
MINERALS—released from soil reserves and recycled	MINERALS—mined, processed, and imported
WEED & PEST CONTROL—biological and mechanical	WEED & PEST CONTROL—with pesticides
ENERGY—some generated and collected on farm	ENERGY—dependence on fossil fuel
SEED—some produced on farm	SEED—all purchased
MANAGEMENT DECISIONS—by farmer and community	MANAGEMENT DECISIONS—some provided by suppliers of inputs
ANIMALS—produced synergistically on farm	ANIMALS—feed-lot production at separate location
CROPPING SYSTEM—rotations and diversity enhance value of all of above components	CROPPING SYSTEM—monocropping
VARIETIES OF PLANTS—thrive with lower moisture and fertility	VARIETIES OF PLANTS—need high input levels to thrive
LABOR—most work done by the family living on the farm	LABOR—most work done by hired labor
CAPITAL—initial source is family and community; any accumulation of wealth is reinvested locally	CAPITAL—initial source is external indebtedness or equity, and any accumulation flows mainly to outside investments

For 9.900 years that line was all the way to the right of the page. Virtually all production on farms came from the renewability and sustainability of the internal resources. Starting 100 years ago. the industrial revolution began to influence agriculture in a big way. So did the mentality of the industrial revolution. Within the short space of about 50 years, in fact, there took place a fundamental switch. Farming became an arena for wide-scale use of inputs.

That switch to an input emphasis in agriculture greatly increased production. And more production was needed to meet the food and fiber needs of the fast-growing human populations of the period. But the switch also introduced a new kind of vulnerability into agriculture. Less important was the old vulnerability primarily attributable to the vagaries of nature. Lack of rain could be remedied by irrigation. Lack of fertility, by fertilizers. Pest attack could be diminished by pesticide use.

But what if the inputs themselves became too expensive or were not available? And what if the side effects of the input use became problems so serious that they aroused wide-scale opposition to the use of input-intensive agricultural methods?

To state the matter very simply, those are the conditions that are beginning to prevail today. They are arousing interest in the question of the sustainability of input-intensive agricultural systems.

Sustainability Is the Problem. Something Else Is the Solution

I like the concept of sustainability as a way to begin talking about the current problems of agriculture. It is one of a number of questions that need to be raised from time to time about the merits and long-term value of any form of human activity.

But is sustainability the solution that people want to today's agricultural problems? About that, I'm not so sure.

The number of mouths to be fed in the world is not likely to be sustained at the present level. It will certainly increase. We are, therefore, going to need much *more* production of food and fiber in the future—not just the sustaining of current amounts.

Do we want to sustain the current quality of the agricultural resource base? Not at all. We must help to make the land better, the air cleaner. our selection of germplasm richer, and the water we drink and use purer. Sustainability, therefore, speaks with a very weak voice to the problem side of the agricultural equation.

And finally, *what does sustainability really mean?*

On the surface. that seems to be a simple question. You simply change agriculture so that farmers are able to keep producing indefinitely.

Okay, but how? Be specific. Tell me exactly how to begin. And tell me which methods will contribute to sustainability in the future and which won't.

Many makers of agricultural research policy today are struggling with those questions. So are farmers. And there is growing frustration. Sustainability. which on the surface seems such a simple concept and goal. turns out in practice to require a much more sophisticated form of analysis than first meets the eye.

My contention is that sustainability is only a part of the right question to ask. Far more important is an analysis of resource renewability. We need to start thinking about what causes resources to renew. How does it happen? Is it automatic? Or does human activity play a role of over-whelming importance in the renewal of agricultural resources.

There is also the question of production cost. Perhaps sustainability can be achieved in one sense—that of producing food and fiber at a certain level. But what will it cost? How expensive will be the inputs needed to make that production happen?

One rather large group of researchers and farmers working on new ways to reduce costs and solve production problems talks very little about sustainability and focuses instead on the regenerative nature of all living systems. Their goal is to make practical use in agriculture of the regenerative tendencies inherent in land and the land-based environment. I am associated with that group.

Our primary view is that those things commonly called renewable resources don't just renew themselves. What actually happens is that they regenerate within a complex environment of living systems. From a research perspective, that adds a significant level of complexity. You can't really understand renewability unless you also begin to understand the nature of the systems in which those resources exist. To help people make practical use of them, a researcher must know about the regenerative tendencies expressed within those systems. And a researcher must also have ideas about how those tendencies can be enhanced and put to practical use.

The benefits of that kind of thinking and research can be enormous. There are actually far more resources that can be regenerated than can renew on their own. And a series of regenerating resources has the capacity to lift the quality of the whole resource base to new levels of quality. In summary, a regenerative approach to an activity like agriculture can move production above mere sustainability to continual improvement well beyond conventional expectations.

Consider nitrogen as an example. Nitrogen is not usually considered a renewable resource of agriculture. In purchasing industrial, nonrenewing resources, farmers spend more money for nitrogen than for any other fertilizing element. Yet air is 78% nitrogen. And nitrogen can be fixed form the air by leguminous plants and also by certain free-living microorganisms. But to make maximum practical use of that tremendous nitrogen resource, the farming system itself must be changed to create what I like to call regenerative situations.

A variety of nitrogen-fixing plants and nitrogen-retaining strategies needs to be introduced at a number of places in the farm system. In fact, innovative farmers and researchers are already working in this direction by over-seeding legumes (and some grasses) in standing row-crops like corn and beans. The legumes reduce soil erosion by providing ground cover during fall and winter. Come spring, they are plowed down as nitrogen-rich, soil-building green manures. Over-seeded legumes also help choke out weeds and conserve soil moisture. When used in a whole-farm system that includes crop rotation, ridge-tillage, and proper manure management, some farmers in the United States are finding that they can produce good crops for total production cost that are up to $95 per acre *less* than normal.

Animals also play an important role. in both United States and Third World agriculture. Even trees are critical in some areas. Many trees are leguminous and have a great potential to substitute for other sources of nitrogen.

But trees do much more than feed the soil. They feed both livestock and humans by producing everything from forage to nuts and fruit. Tree crops are especially well-suited for erosion-prone hillsides. But even in flatlands, tree crops are being planted with annual field crops. This "two-story agriculture" produces—and earns—more than separate plantings of trees and field crops. Later, the trees provide fuel to cook food and heat homes and even the lumber to build our homes.

And nitrogen is not the end-point of resource regeneration in agriculture. It is just the best place to start understanding the process. In fact, every single internal resource listed on the chart I have presented has some regenerative capacity, starting, of course, with the sun, which blesses us with light and warmth through the action of continually regenerating fusion reaction.

Economics Is Critical

Agriculture has proven to be fertile ground for the regenerative approach to resource understanding and use because it makes good economic sense. In agriculture, the alternative to resource regeneration is to purchase inputs. Back in the 1960s and early 1970s, that often made the best economic sense. Inputs were cheap, the commodity prices for farm products were high.

But that situation changed drastically with the oil embargoes of fifteen years ago. Within a few years, it became apparent that input costs had risen and would stay high, while a perverse set of conditions conspired to keep farm commodity prices low. So the logic of finding new ways to regenerate the resources needed for agricultural production became very clear. Farmers started asking quite loudly for lower-cost production methods. Agricultural researchers began to be pressured to find new ways to meet those demands.

The results of that effort are encouraging. Regenerative resource methods are not extreme. They do not require drastic initial shifts in farming techniques. Farmers are invited to move toward them step by step and also to participate directly in the research process. There is not a strong move to eliminate input use totally—a great fear of both farmers and input suppliers. The emphasis instead is on changing the way inputs are used so that they no longer diminish the vitality and regenerative nature of the internal resources of farm systems.

Again, the nitrogen economy provides a useful example of that change. Nitrogen fertilizer is not only expensive and potentially damaging to the environment. If overused, or used wrongly, it can diminish that strength of internal nitrogen-fixing and -retaining tendencies within the land. Too much nitrogen from external sources in effect sends a clear message to the nitrogen-fixing capacity within the land to work less hard. That is costly to farmers.

The Universal Nature of Regenerative Tendencies

When agricultural land is allowed to rest and regenerate, seven specific things happen:

- There is an increase in the diversity of plant species.
- The surface of the soil becomes covered with plants, ending erosion and increasing beneficial microbial populations near the surface.
- Without chemical fertilizer and pesticide use, a greater mass of plants and other life exists in the soil.
- More perennials and other plants with vigorous root systems begin to grow.
- Past patterns of weed and pest interference with growing systems are disrupted.
- Nutrients tend either to move upward in the soil profile or to accumulate near the surface, thereby becoming more available for use by plants.
- Overall soil structure improves, increasing water-retention capacity.

Those regenerative tendencies have become the basis for the creation of regenerative systems of agriculture. To the greatest degree practical, researchers study the specific regenerative tendencies individually. As the usefulness of the specific tendencies becomes understood, farming techniques which enhance them are introduced into the production system.

That basis in the specific renewal tendencies of a resource-based system gives regenerative agriculture a clear definition and solid conceptual roots. The problem of defining exactly what regenerative agriculture is, therefore, becomes much simpler.

Most fascinating and useful, though, is the fact that regenerative tendencies appear to be mirrored in all living systems and even in the motivation and life experiences of people. A good example is embodied in the second chart, listing the seven regenerative tendencies within agricultural systems, communities, and the human spirit. I wrote the portion of the chart relating to agriculture. My daughter, Maria Rodale, who is working to understand the nature of regenerative tendencies within human communities and in the human spirit, pointed out to me that similar tendencies appear to be universal facts of life.

That comparative analysis of regenerative tendencies is but one small example of the rapidly expanding literature in this intriguing field. The fast-growing range of activity by farmers and researchers on regenerative farming systems is being matched by an equal or even larger growth in interest in other regenerative systems. And what is most exciting about this new line of thought is that old distinctions between disciplines, and other arbitrary conceptual separations, are falling by the wayside.

A new way of thinking about and using what we used to call renewable resources is being created. One goal is sustainability. But the full meaning of the effort can only be sensed through an understanding of the great regenerative potential of the earth itself and of the living systems in it.

A Conceptual Framework for Regional Analysis for Semiarid to Subhumid Agroecosystems

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INTRODUCTION

Science must direct its attention to the problems associated with land-use and atmospheric change in order to:

- better understand the processes of ecosystem and climate change;
- better predict the consequences of these changes in both environmental and socio-economic arenas: and
- provide plans for maintaining global. regional and local ecosystem integrity and sustainability (WCED 1987).

This paper discusses how we might address one aspect of land/atmosphere changes—that of the functioning of agroecosystems. It also suggests a framework with which this integration could be accomplished. It utilizes a novel approach to the question of how one documents change in ecosystem properties, while simultaneously setting up a means to predict the significance of these and future changes

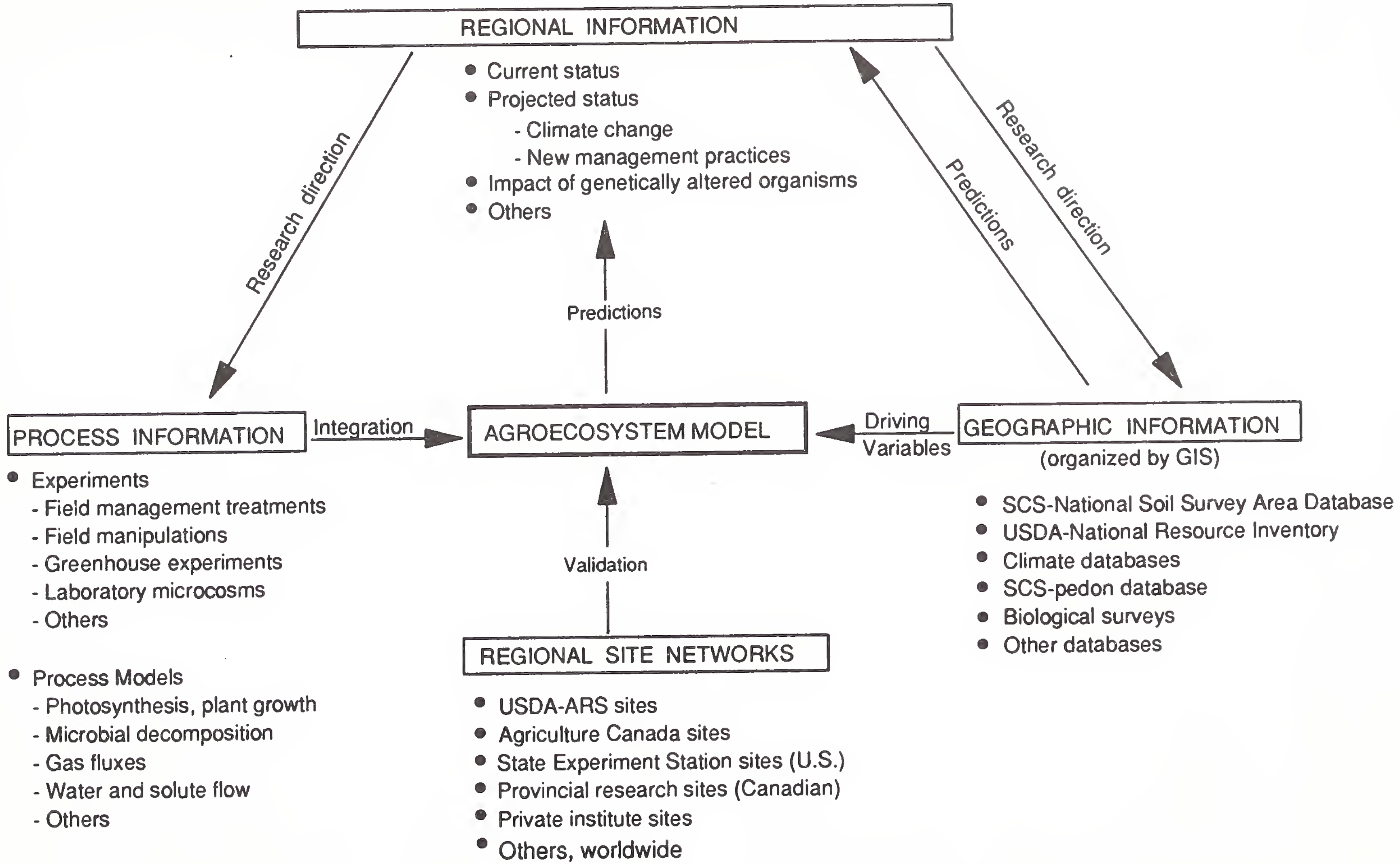

Figure 1. Information requirements and structure for long-term and large-scale analysis of agroecosystems (taken from Elliott and Cole 1989).

on land quality and sustainability. This approach will require interdisciplinary research and therefore utilizes the data bases, process studies, models, and experience of a collaborative network of scientists (Elliott and Cole 1989; Fig. 1). The Great Plains area of North America is a very fragile agroecosystem that has already been subjected to considerable degradation and change as the result of a combination of management decisions and climatic change.

The critical issue is: Do we understand the functioning of the agroecosystems of the North American Great Plains well enough to manage them for productive and sustainable agriculture given the cyclical nature of the weather patterns and the intensive use of the land? Equally important is the question, "Have we organized our knowledge in a way that encourages technology transfer to managers of the region?"

Some conservation principles are already in practice as there has been a shift to agroecosystems that reduce soil disturbance and optimize crop to unplanted fallow ratios, minimize evaporative soil water losses and more closely mimic the stable, native ecosystems of this region. Management practices change in accord with these principles of moisture conservation and reduced soil disturbance along environmental gradients such as the transect from semiarid to subhumid in the northern Great Plains. Agroecosystems are intentionally disturbed ecosystems that are being forced to states different than the natural systems from which they are derived. The major driving variables are tillage, crop management and changing climate patterns. These long-term ecological changes are not easy to predict or measure, but through the use of process studies, simulation models and large scale databases organized with geographic information systems, it is possible to determine 1) the current status of the agroecosystems of the Prairies, 2) how this current state was reached and, 3) long-term effects of new management practices, changing weather patterns and impending climate change (Elliott and Cole 1989).

BACKGROUND

At present both Canadian and US scientists have an informal network in place which has, over the past decade, evaluated and refined aspects of ecosystem science (Anderson et al. 1983. Anderson 1988, Cole et al. 1987, Stewart 1984, Stewart 1987, Tiessen et al. 1984). During the past decade, we have been studying soils developed on former grasslands and bordering forest soils of the Great Plains of North America. The overall objective of these investigations (Stewart et al. 1983a) was to develop concepts and procedures in quantitative pedology and to test these concepts on a small number of soils selected along climo-, topo- and cultivation chronosequences. This has allowed us to expand on the ideas of Jenny (1980) on driving variables or soil-forming factors and to integrate them with hierarchical perspectives used to describe ecosystems.

Much of our efforts have been directed to studying organic matter dynamics. Some of this work has focused on understanding processes involved in the interrelationships among carbon (C), nitrogen (N), sulfur (S) and phosphorus (P) in nutrient cycling. Dynamics of these elements have been related to organic matter stability and quality as soils have developed in the Great Plains area of North America and how these changes are effected under different cultivation systems.

Most of the model development has been led by a group of ecosystem scientists (Cole et al. 1977, Hunt et al. 1983, Hunt et al. 1986, Parton et al. 1983, Parton et al. 1988, Parton et al. 1989) that make up the Great Plains project. This, the third in a series of projects which began in 1979, has provided an integrative research structure within and between Colorado State University (CSU), University of Saskatchewan and federal agencies in both countries. We suggest that the time is now opportune to formalize currently ongoing cooperation among the Agriculture Canada research stations and Universities in the prairies of Canada, Colorado State University, and the USDA-ARS and SCS in the United States. Furthermore, everyone involved could benefit from this cooperation if it can be organized to be interactive with established inventory bases and predictive simulation models.

Since their inception, Federal research stations (Agriculture Canada and USDA-ARS) have completed many valuable long-term studies (Campbell et al. 1989, Haas et al. 1957). There are a number of ongoing, long-term studies of cropping management systems. It will be possible to integrate and synthesize considerable amounts of information on long-term dynamics of agroecosystems without having to wait many years for research sites to mature. This approach could serve as a focus for semiarid agroecosystem research in North America for many years to come.

Processes and Interactions

Much of our research in the past decade has been focused on elemental transformations of C, N, S, and P within a framework of ecosystem properties and their driving variables, (defined as external factors that govern the processes that operate in a particular environment). The general hypothesis is that the effects of driving variables are expressed through their influence on ecosystem processes. These processes include above- and belowground primary production, decomposition and nutrient cycling. Major driving variables include climate (temperature and water), parent material (soil texture), base status, total S and P, topography and management (Stewart et al. 1983a and Stewart et al. 1983b). The effects of these controlling factors are expressed over a wide range of resolution from the global down to regional, landscape, field plot, and microsite levels. Our research has therefore concentrated on understanding the processes and element interactions in organic matter dynamics (Stewart 1984, Elliott 1986, Cole et al. 1987, Stewart and Tiessen 1987, Stewart and Cole 1989) and the development of conceptual and mathematical simulation models (Parton et al. 1983, Parton et al. 1989; Hunt et al. 1983, Hunt et al. 1986) which were used to focus attention on controls of important processes and to test hypotheses.

Inorganic inputs, internal nutrient recycling and leakage of nutrients through leaching from surface soil layers are aspects of nutrient cycling that determine the efficiency with which nutrients are used for plant growth in agroecosystems. Where the soil organic matter can no longer provide enough nutrients for plants, fertilizers are applied. Timing, amounts and placement of fertilizers have been thoroughly studied and there is extensive information available. However, there has been little work done on integrating the use of fertilizers with internal recycling pathways through management of microbial biomass and crop residues in conservation tillage systems.

Changes in soil structure resulting in more continuous pore networks under no-till management change the hydraulic properties of soils, the interaction of solutes with the soil solution and, therefore, the movement of inorganic nutrients through the soil profile. With the development of continuous macropores resulting from roots and earthworms, incoming rainwater moves quickly through the surface horizon and mixes less with the interstitial soil solution than where the lack of continuous pores results in slower downward movement of water. Rainwater moving through soil managed under no-till can result in less leaching of nitrates than under conventional tillage, as we have observed at the Sidney, Nebraska field-site (Elliott and Coleman 1988). Shifting to no-till management and better soil structure presents opportunities for less leaching of nutrients and more efficient plant uptake of nutrients from soil surface layers. If agroecosystem models are to accurately depict movement of inorganic ions they will have to be modified according to the type of management used, the ability of the soil to develop macroporosity and the amount of time the soil has been exposed to a particular management practice. Nitrogen fertilizer use in dryland farming in the Great Plains has increased dramatically since 1970. This is in response to declining mineralizable soil nutrients and increased demand due to higher yielding varieties. Increased fertilizer use with reduced soil fertility, means narrower profit margins for farmers. There is increasing recognition of the problems present in agricultural systems of the Great Plains and the entire North American region. New programs administered by Federal governments will attempt to reduce soil loss to tolerable levels by the early 1990's. These programs necessitate adoption of reduced and no-till management systems. Surface soil cover by crop canopy or crop residue for most of the year will become the norm. Instead of only managing the crop, farmers will be managing crops and residues. Application of systems management concepts are increasingly important.

Less tillage coupled with increased herbicide use results in decreased soil loss, improved infiltration with less water runoff, less evaporation, increased potential for plant biomass production and the possibility of increased water percolation through the soil profile. It is widely accepted that improved residue management saves water from runoff (Fenster and Peterson 1979, Smika 1970, Smika and Whitfield 1966, Smika and Wicks 1968). However, improved infiltration can allow more water to penetrate than the soil can retain. Therefore, alterations in cropping systems; for example, rotations with more crop periods and fewer or shorter fallow periods (Peterson et al. 1990), are needed that will ensure plant use before deep percolation and associated saline seep can occur.

Databases

In Canada, two regional data bases, the Agricultural Resource Areas (ARA) map at the scale of 1:2 million and the Generalized Soil Landscape Map (GSLM) at a scale of 1:1 million are available for the Great Plains area. These databases include information pertaining to soil and landscape characteristics, land use and climate. A list of the component soil series within each polygon provides a link to the soil series or pedon database. A comprehensive database for all the 1:100,000 scale maps for the prairie region is also contained within Canadian Soil Information System

(CANSIS). The map unit component contains information on the areal extent, slope, stoniness as well as the extent of individual soil types or series. The soil series component contains chemical, physical and morphological attributes by horizon for each individual soil type, including particle size, organic C, pH, CEC, water retention, bulk density and carbonate content.

The individual "map layers" described above can be used to form a composite GIS that integrates soils, climate, and management data to a single scale of resolution. Overlay procedures in ARC/INFO (e.g., UNION; Environmental Systems Research Institute, Redlands, CA) can be used to combine the component map layers, producing a dense polygon map. The resulting composite polygon attributes can then be extracted and subjected to an external classification procedure, producing 100-500 classes of polygons, each with corresponding climate, management, and soils attributes. This approach has been applied by Burke et al. (1990) and will be discussed later.

The ARC/INFO geographic information system (GIS) is the most diverse and widely used in the United States and Canada today. It has sophisticated capabilities for building topology from a wide array of database types, as well as a database management library system. Government and private offices, including the SCS and EPA, are using ARC/INFO to build spatial databases. It is a system that is well-suited for the purposes of integrating multiple data sets across the Great Plains. In Canada ARC/INFO is being used by Agriculture Canada LRRC in Ottawa as a means of storing and making interpretive use of the Canadian Soil Survey Inventory. It has also been adopted by other federal agencies to integrate forest and other inventories. More importantly, other systems that are being considered for database management are for the most part compatible with ARC/INFO. Thus, it should be possible to utilize a variety of existing data bases using this system.

Development of CANSIS began in 1973 as a cooperative project between the Land Resource Research Centre (LRRC) of Agriculture Canada and the soil survey units in each of the provinces. Currently, soils information for the bulk of the agricultural and productive forest region of Canada is contained in the ARC/INFO geographical system maintained by LRRC and accessible by the provincial units. Development of the National Soil Survey Area Database (NSSAD) began at Colorado State University in 1977, as a cooperative project among the U.S. Department of Agriculture, Soil Conservation Service and the College of Agricultural Sciences. What began as a pilot effort at CSU to organize and enhance the availability of soils data for the State of Colorado is now a national program. Currently, soils information for approximately 2500 of 3000 soil survey areas in the U.S. are contained in a single database under the management of the System 2000 (S2K) database management system (MRI Systems Corporation, Austin, TX). NSSAD has two components of significance to our proposed research. The first is the map unit component which consists of site-specific descriptions of individual soil types (series). These descriptions include information pertaining to the soil physical setting, horizonation, areal extent, predominant land use, crop type, and crop yield. The second component is the soils interpretation record which contains interpretive information for each individual soil type. Included are such attributes as available water capacity, mineralogy, soil temperature, and particle size distribution.

In addition, CSU has developed a database which contains chemical and morphological attributes (organic C and N, sand, silt, clay and bulk density are included by horizon for each soil) for approximately 300 cultivated and 500 uncultivated soils of the U.S. Great Plains. Also available is an extensive climate database using long term data from U.S. Weather Bureau summaries. This database includes mean annual and growing season (April through September) precipitation, temperature and potential evapotranspiration (after Linacre 1977) for approximately 560 weather stations in the U.S. Great Plains. A measure of site productivity (Sala et al. 1988) and decomposition (Parton et al. 1987) are included for each station. Similar data are available in Canada.

Predictive Simulation Models

The Century Model (Parton et al. 1983) was developed to simulate soil organic matter dynamics and plant production in grazed grasslands and agroecosystems. The data used to develop the model came from long-term incubation studies of 14C-labeled plant material in different soil types (e.g., Sorenson 1981, Ladd et al. 1981, Stott et al. 1983), soil carbon-dating (Martel and Paul 1974), soil particle size fractionation (Tiessen et al. 1982, Tiessen and Stewart 1983), and modelling studies at different levels of resolution (McGill et al. 1981, Van Veen et al. 1984, Cole et al. 1977, Parton et al. 1983). The Century soil organic matter model simulates the dynamics of C, N, and P in the soil-plant system using monthly time steps. The input data required for the model include soil texture, monthly precipitation, maximum and minimum air temperature, and plant lignin content. The Century Model has been used to simulate regional patterns of soil C, N, and P and plant production for the U.S. central grasslands region (Parton et al. 1988, Parton et al. 1989) and the impact of management practices on agroecosystems (Cole et al. 1989).

The Century Model has also been used successfully to simulate the impact of cultivation on agroecosystems in the United States (Cole et al. 1987), Canada (Parton et al. 1989), and Sweden (Parton et al. 1983). The model includes the direct effect of cultivation events on nutrient cycling and soil organic matter dynamics. The direct impacts include incorporation of standing and surface residues into the soil, modification of soil temperature and soil water patterns, and increasing the turnover rates of soil organic matter. It should be possible to add the interactive impact of tillage, cropping systems, and soil texture on decay rates of soil organic matter and validate the ability of the model to simulate these impacts by comparing simulated effects with detailed soil organic matter, nutrient cycling and plant production data from our Regional Research sites.

Other models, such as the Grassland Ecosystem Model (GEM), represent important feedbacks among primary production, photosynthetic pathways, water use, decomposition, and nutrient cycling processes. It is more mechanistic than the Century Model. For example, it includes mycorrhizae and soil fauna, and uses more mechanistic translocation, nutrient uptake, shoot and root death and decomposition processes. This model has been applied to analyzing the difference in primary production and nutrient cycling patterns between native shortgrass prairie and introduced crested wheatgrass in Wyoming. The GEM model includes the level of mechanism necessary to serve as an aid for interpreting differences in production and nutrient cycling among different crops and sites. It has also been used to predict the effects of climatic change on grasslands (Hunt et al. 1990).

An important cropping systems model is the Nitrogen, Tillage and Residue Management simulation model (NTRM) (Shaffer and Larson 1982, Shaffer et al. 1983, Shaffer 1985) which is designed to provide research capabilities for studying physical, chemical, and biological processes and their interactions. The model can be used to quickly determine environmental impacts and provide direct management assistance to farmers in an interactive version, COFARM (Shaffer et al. 1984). It has been used to simulate many processes such as the decay of crop residues and recycling of C and N using methods described by Shaffer et al. (1983) and Molina et al. (1983). The crop growth submodel consists of a series of subroutines capable of simulating the growth and development of field maize, sweet corn, sorghum, soybean, spring and winter wheat, oat, barley, rye, sunflower, alfalfa, pasture grass, sugarbeet, cotton, peanut, tomato, field pea, sugarcane, sweet potato, and carrot. NTRM is capable of simulating any combination of these crops in rotational sequence. Several years of simulation can be run to estimate the impacts of crop rotation on various parts of the system. The model can also be used in studies involving NO_3-N loading of groundwater (Shaffer 1979).

NTRM model inputs include climate data such as daily maximum and minimum air temperatures, pan evaporation, precipitation, wind run, and solar radiation. Values must be provided for soil physical, chemical, and biological properties of user-specified soil horizons. The NTRM model contains crop submodels for growth of tops and roots as a function of climate and soil variables. Processes simulated include photosynthesis, respiration, growth of leaf area and stover, grain filling, transpiration, and N uptake. The root growth submodel (Shaffer 1987) includes root extension, branching, and death. The impacts of soil tillage on the physical, biological, and chemical properties of the soil using both tillage submodels and specific relationships within other subroutines (Shaffer and Larson 1982). Changes in certain soil "macro" properties such as bulk density, percent organic matter, and texture are translated into changes in other properties such as the soil water characteristic curves, C and N transformation rates, soil water content, soil strength, soil aeration, and nutrient and salt concentrations.

Ideally, the process level information embodied in simulation models should be linked to geographic information to better understand regional dynamics of element cycling. This work has just begun. The Century model was coupled with the ARC/INFO GIS to model regional biogeochemistry of grasslands (Burke et al 1990). Model inputs obtained from the GIS were soil texture, monthly precipitation and monthly minimum and maximum temperatures. Polygon maps of the driving variables were overlain to produce a driving variable map of the studied region (northeastern Colorado). The final 768 polygons were placed into 160 unique classes and used to drive the model. At steady state, net primary production appeared to be controlled most strongly by precipitation patterns while soil organic matter was controlled mostly by soil texture within this region. Such regional models are needed to relate process level information to global scales.

CONCLUSION

It would appear from the above discussions that the methodology has already been developed, tested in part and that this innovative approach will enable us to understand the functioning of agroecosystems. This is an encouraging start to the task before us. We have now to channel more effort into this approach and especially into the technology transfer mechanisms (Fig. 2) that will unite theoretical approaches with practical action such as is envisaged in the Soil Conservation and Management Program.

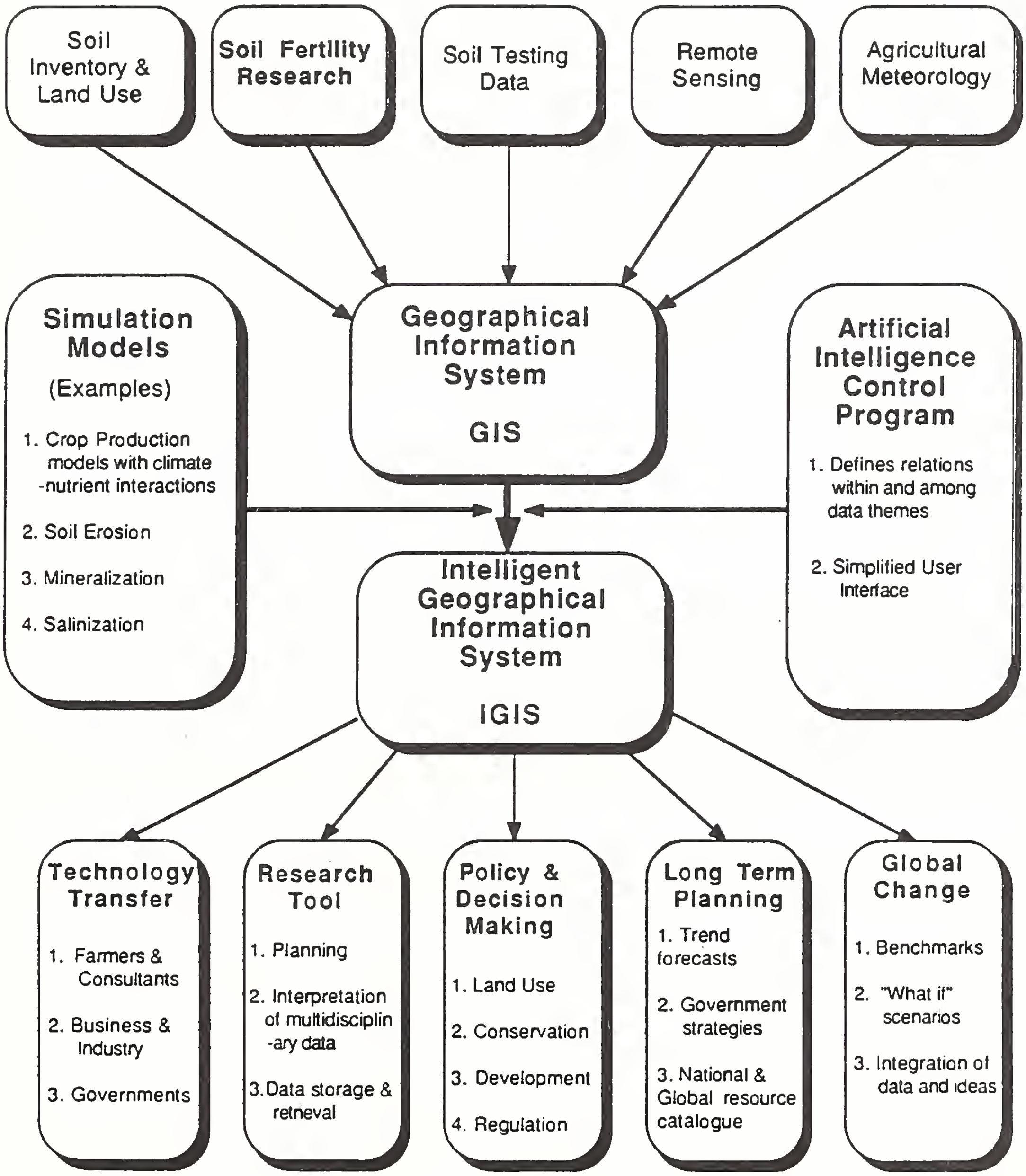

Figure 2. Schematic for managment information used for technology transfer to users of agricultural ecosystems.

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New Directions in Soil Management Research

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It is very appropriate after approximately 100 years of arable agriculture in most areas of the Great Plains, that the focus of this symposium be on the sustainability of agricultural production systems. Historically, it has been political and socioeconomic incentives, and competition among producers that have fostered production-oriented research, probably at the expense of developing low-energy-input systems having equal or superior long-term production capabilities. From a research perspective, one of the most pertinent question to be asked appears to be "what types of conservation production systems and technologies are needed to sustain arable agriculture in the Great Plains for the next 100 years and beyond?". The continued loss of the soil resource to erosion in this region is alarming. Most recent estimates are that soil erosion is occurring at rates in excess of soil renewal levels on 48-million acres due to wind and on another 28-million acres due to sheet and rill erosion from water (USDA-RCA 1987). This means that 70% of the Great Plains arable acreage is currently eroding at a faster rate than the soil renewal processes are functioning to replace it. Based on this information, one would have to conclude that current production systems are not sustaining the soil resource, and that improvements in management are needed.

Before addressing soil, water, and crop management problem areas and future research challenges, some of the external factors, constraints, and controls that will be imposed on agricultural production systems need to be identified. Future research initiatives likely will be impacted by the following four factors:

1. Economic/Government Farm Policies
    a. Will government farm policies continue to foster monoculture or single- or two-crop rotations?
    b. Farm product market values or government subsidies, or both, may not increase sufficiently to keep pace with the increasing costs of current high-energy-input production systems.
2. Higher energy costs are predicted which subsequently will increase the cost of fuel, fertilizer, and pesticides above current levels.
3. Greater public concern for environmental protection which will be reflected in even more regulatory and compulsory limitations on use and availability of pesticides and all agricultural chemicals than those currently in place.
4. Greater public concern for quantity and quality of surface and sub-surface water supplies for domestic, recreational, and agricultural use, which will cause more restrictions on fertilizer and pesticide use and perhaps limit the quantity of water available for agricultural purposes.

A research needs perspective for Great Plains Agriculture was given by Dr. J. R. Johnston, (retired) at a USDA-ARS Operational Planning Workshop on Great Plains Conservation-Production Systems November 5-7, 1984 at Denver, Colorado advocating eight major areas of research needs. These were as follows (*verbatim*):

1. By use of advancing computer technology and systems science, generate weather and climatic models which will permit effective soil and crop management decisions on a daily, monthly, and yearly basis.
2. Redefine the meaning of soil erosion, giving special attention to the grossly inadequate expression of "tons of soil loss per acre" and move away from the negative base of "clean tillage on a 9% slope" toward a more positive base of perennial vegetative cover and conservation tillage practices.
3. Generate a more complete knowledge base regarding effective use of water in the evapotranspiration process (ET) with full expectations of reducing evaporation and increasing transpiration in conservation and production systems.
4. Focus sharply on knowledge and technology that will permit Great Plains agriculture to become energy self-sufficient and less dependent on fossil fuels to power its agriculture.
5. Go all out in use of genetic variability in plants and animals to provide an ever expanding base of germ plasm for full and effective use of soil, water, and energy resources in optimizing conservation and production for all agricultural ecosystems in the Great Plains.

6. Make an all out effort to determine the "Production Potential" of all important natural and modified ecosystems in the Great Plains so these basic data sets can be used in generating optimum conservation and production systems.
7. Develop and exploit technology to reduce the adverse impacts of weeds, insects, diseases, nematodes, and rodents in achieving the full production potential of conservation and production systems.
8. Develop effective multidisciplinary teams of biological and physical scientists along with economists for generating optimum conservation and production systems for all agricultural ecosystems in the Great Plains.

While these eight major areas of research needs for the Great Plains remain as valid guidelines for research, we need to be certain that future research not only addresses these needs, but also, that the research addresses major regional problems that are counter to sustainable crop and livestock enterprises. Many of the major problems of the Great Plains are interrelated so that research efforts focused on one problem may assist in solving other problems. Interdisciplinary team research would appear to be the superior approach to problem solution.

We view the following as major problems which counter sustainable arable Great Plains agriculture for the future and provide a brief description of some possible research strategies to alleviate these problems. These are presented for discussion purposes as follows:

1. Soil Erosion (Wind and Water)

   The dynamic processes of soil erosion are well documented. But the interactive effects of climate, conservation tillage system, soil textural class, and vegetative cover on soil erodibility over time sequences still remains to be adequately researched and documented. Changes in soil organic matter content over time may be a better index of loss of soil and soil productivity to erosion processes than the presently utilized T value (annual average soil loss, tons/acre).

2. Water Conservation/Efficient Use

   Documentation and development of data bases, complete with how and when water conservation occurs in relation to the evapotranspiration processes and of crop water use by plant development stage, are needed for conservation tillage-crop production systems involving simple and complex crop rotations. This knowledge base is urgently needed in designing appropriate conservation tillage crop rotations to use in lieu of monoculture cropping systems.

3. Surface- and Ground-Water Degradation

   In lieu of characterizing water degradation problems, research should be directed toward preventing the occurrence or alleviating the cause of water quality problems. Researchable examples are: the development of more effective methods of utilizing crop residues for water conservation and erosion control; the development and use of crop rotations that would include both shallow- and deep-rooted crops to match water and nitrogen supplies; and the timing of application of fertilizer nitrogen to coincide with plant need. These would constitute research approaches aimed at the very cause of some of the water quality problems associated with movement of salts and nitrates.

4. Monoculture Cropping Systems

   The closer a crop rotation approaches a monoculture, the greater is the need for high-energy-input entities to control weeds, insects, diseases, etc. Research is needed to develop a knowledge base in the use of diverse crops in rotations with wheat (all classes) to break weed, insect, and disease cycles. Cropping strategies which reduce the need for high-energy-inputs, including the use of cover crops (leguminous or nonleguminous), need to be developed for efficient use of water and nutrient supplies and for erosion control.

5. Soil Productivity/Declining Organic Matter/Nutrient Cycling

   More effort should focus on developing data bases quantifying inherent soil productivity of major Great Plains benchmark soils for both rangeland and cropland. These data bases would serve as a basis for evaluating which management systems and practices would be the most appropriate for stabilizing or rebuilding soil productivity. Sustainability of agricultural systems will be determined by soil organic matter/soil erosion relationships.

6. Salinity

   Salinization of soils utilized for croplands under rain-fed and irrigated management systems is a recognized problem throughout the Great Plains. Research is needed to identify the cause and then develop appropriate water-plant management practices to stabilize or alleviate the problem.

7. Pests (Weeds, Insects, and Diseases)

   Interdisciplinary research teams need to be established at key Great Plains locations to define and describe pest cycles as affected by various conservation tillage-crop rotations. Germplasm enhancement of grasses, forages, and grain crops is a continuing need to identify pest-resistant-high-yielding cultivars which minimize the need for tillage and pesticides in conservation production systems. The overall goal is to reduce production costs by minimizing the need for tillage and pesticides.

8. Suboptimal Water- and Nitrogen-Use Efficiencies

   In lieu of evaluating nitrogen-use efficiency (NUE) solely on a one-time individual crop response basis, an exact assessment of the impact of crop rotations on NUE should be made considering all soil and plant N pools. Studies directed for evaluation of the impact of crop rotations on water- and N-use efficiencies are needed to better quantify the inter-relationship of crop root-zone depth and its characteristics, soil water and soil nitrogen, and the contribution and sources of all N pools to plant uptake within the agroecosystem. Several crop rotation cycles are needed because of the strong interaction of climatic variability from year to year. Nutrient use-efficiency of other macro-nutrients, particularly P and K, need to be studied in the same manner in conventional- and conservation-tillage crop rotation systems.

9. Vagaries of Great Plains Climate/Reducing Drought Impacts

   Crop production level in the Great Plains is governed primarily by the water supply available to the crop and how efficiently that supply is utilized.

a. Research needs to be continued to (1) identify those water conservation strategies that are most efficient in storing the rainfall and snowfall received on the land and (2) develop companion crop or grassland management systems that produce more usable plant material per unit of available water. (Stored soil water plus growing season precipitation.)

b. Land modification practices for control of run-off water have been developed and evaluated from an agronomic viewpoint but assessments of the socioeconomic aspects have neither been adequate nor quantified.

c. Augmentation of water supplies by weather modification has potential in orographic regions. With present technology, potential in the Great Plains region appears limited.

CONCLUSION

The nine problems counter to sustainable agriculture that we identified to challenge research scientists in the Great Plains may not be inclusive of all of the problems to be addressed. A commonality that should not be overlooked is that many of these problems and research challenges are interrelated, directly or indirectly. Therefore, future progress in solving such problems can best be accomplished using a coordinated interdisciplinary research approach at key locations in the Great Plains. Modelling efforts need to be coordinated with field and laboratory research projects to provide assistance in interpreting experimental results, defining where knowledge gaps are evident, testing new hypotheses, designing new experiments, and making predictions concerning management practices.

Much of the suggested research requires long-term commitments (6 to 12 years minimum) in order to obtain the appropriate data sets needed. Experience has also taught us that soil conservation and water conservation are inseparable in the Great Plains and research on either aspect must complement the other. The sustainability of agriculture in the Great Plains in future years will depend on the development of appropriate conservation production technologies and government farm policies that will foster adequate protection of the soil and water resources.

Role of Water in Great Plains Agriculture

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ABSTRACT

Water is the major driving variable controlling agricultural production in the Great Plains. The region has prospered and "busted" in cycles tied to the availability of water supplies. Yet, the historical record shows that periodic short and long-term droughts can be expected throughout the region. Advances in crop genetics and agricultural management techniques have sharply increased grain yields relative to those of the first third of the century, and have provided some buffer against drought. However, the impacts on crop production of a major drought affecting the majority of the region over a period of several years have not been evaluated. This paper shows how simulation modeling combined with geostatistics and GIS mapping can be used to help evaluate these impacts and suggest management techniques that minimize crop and range losses.

INTRODUCTION

Of all the driving variables controlling agricultural production in the Great Plains, water is the primary force. Indeed, the fate of agriculture in the region is closely tied to the occurrence, distribution, and management of this scarce resource. Historically, dryland agricultural production has gone through periods of relative prosperity followed by periods of "bust" as drought cycles reduced crop and range production. To help stabilize this problem on selected croplands, irrigation was introduced into the region by utilizing water both from surface storage reservoirs and from ground water resources. Unfortunately, ground water reserves are effectively being depleted (mined) faster than recharge can occur, and there is stiff competition for limited surface water supplies from wildlife, municipal, and industrial interests.

Experience with recent droughts underscores the vulnerability of Great Plain's agriculture. For example, the drought of 1976-1977 produced dust storms and erosion levels in the Great Plains that were as severe as the 1930's, Lockeretz (1978). The recent drought of 1988, centered in the Midwest and northern Plains, was the worst short-term drought since 1936, Kunkel and Angel (1988). It pointed to potential problems with agricultural production and food supplies should a widespread drought occur over a period of several years. Given the current depressed farm economic situation in the Great Plains, the question has to be asked "can Great Plain's agriculture survive another drought similar to the 1930's?" The purpose of this paper is to review the role and influence of water on agricultural production in the Great Plains and suggest a mechanism to study and minimize the effects of future droughts.

CLIMATE PATTERNS

Annual precipitation in the Great Plains region varies from about 850 mm in the southeastern portion to less than than 250 mm in the northwestern parts. The majority of the rainfall occurs during the summer months from thunderstorms driven by moisture from the Gulf of Mexico and from the Gulf of California—Pacific Ocean area. The majority of the region is classified as semiarid with the wetter areas being subhumid and drier areas containing pockets of arid climate. Periodic drought cycles have been recorded throughout the historical record. Direct precipitation records date back to the early 1900's with tree ring inferences dating to at least 1700. At least a dozen or more significant drought cycles have been recorded during this period, Stockton and Meko (1975). Recent examples include, the major droughts of the 1950's, 1930's, and early 1900's that impacted the Great Plains over several years. The drought in the mid-1930's was the most widespread over the region in two centuries, Stockton and Meko (1975). The 1988 drought regionally affected the Northern Plains and parts of Texas, but only lasted about a year, Changnon (1989). The drought of 1976-1977 caused severe crop losses and dust storms in the central and northern Plains, but was quickly followed by a wet rainfall cycle, Lockeretz (1978). Pockets of drought occur within the Great Plains on almost an annual basis. These can have severe impacts on local economies, but may not significantly affect the region as a whole. Future climate patterns for the Great Plains are uncertain, but very likely will include periods of drought similar to those previously experienced. Current concern with human-induced global climate change further points to the possibility of a warmer, dryer period for the Plains.

CROP YIELDS

Wheat yields in the central Great Plains have increased from about 16 Bu/acre in 1916-30 to about 40 Bu/acre in the 1976-90 period, Greb (1979). Higher yielding wheat varieties coupled with improved methods of soil water storage, soil fertility management, and planting and harvesting have accounted for most of these gains, Greb and Zimdahl (1980). However, these higher yields are obtained primarily in years with sufficient precipitation. Drought can severely limit wheat yields even under management conditions that exist today. For example, during the 1988 drought, wheat yields in the northern Great Plains were reduced about 50% from yields obtained in a normal precipitation year, Walker (1989). Similar percentage reductions were experienced in eastern Colorado during the 1976 drought. A continuous drought lasting several years would be expected to have even more severe effects as soil water reserves are depleted and wind erosion effects become more pronounced. For example, during the 1950's drought, counties in eastern Colorado experienced yield reductions of 95% or more. The impact of a multiple year drought similar to those of the 1930's and 1950's on crop production, air pollution, and economic stability in the Great Plains region as a whole needs to be evaluated so that measures can be taken to minimize any adverse effects.

SIMULATION MODELS AND AVAILABLE DATA

Current crop management techniques in the Great Plains have produced significantly increased crop yield levels as compared with the early parts of the century. However, other than in single year and localized drought cycles, these methods have not been adequately evaluated for a multi-year drought over the entire region or over significant subregions such as the northern, central, or southern Plains. Most field experiments must, by necessity, wait for a major drought before appropriate data can be collected. Other techniques such as the use of rain-sheltered plots have not been used extensively nor do they include the effects of changes in air temperature and humidity.

Recently developed computer models of the soil-crop and range systems provide the capability of simulating the effects of long term drought stress on crop and range production in the Great Plains. Examples of appropriate soil-crop models include, NTRM (Shaffer and Larson 1987), CENTURY (Parton et al. 1988), EPIC (Williams et al. 1984), CERES-Maize (Jones and Kiniry 1986), and a model for wheat production in western Canada, Walker (1989a). Range production models are available such as SPUR (Wight and Skiles 1987, Hanson et al. 1988). Examples of regional drought studies already completed with these models include NTRM long-term simulations for the Plains reported by Larson et al. (1983) and a western Canada wheat modeling study published by Walker (1989b). Results from these studies are encouraging and demonstrate how models can be used to study the impacts of drought on crop production.

Sufficient data are available in existing data bases to conduct most simulation model studies. For example, historical climate data on daily precipitation and air temperature dating back to the early 1900's are available on CD-ROM data bases. An even more geographically extensive CD-ROM subset of climate station records is available from the late 1940's. Appropriate data on soil properties are available on a combination of the SCS Soils-5 and Soils-6, and Pedon data sets. Work is nearing completion to make this information available on Geographical Information System (GIS) files at a scale of 1:250000. More detailed GIS mapping files are under development at a scale of 1:24000. Published agricultural statistics dating from the 1920's to the present can provide needed information on historical grain production and range conditions. Detailed information on site-specific responses of grain production to climate, soils, and management is available from USDA and university research stations and plots located throughout the region. Site-specific range information is available from research plots and from the Central Plains Experimental Range (CPER).

DISCUSSION

When coupled with analysis and mapping techniques available in GIS applications, the crop and rangeland models can be used to estimate the production of wheat and other crops, and rangeland vegetation grown in the region or subregions over a period of several or many years. Historical drought cycles such as those of the 1930's and 1950's as well as the entire historical record can be used to test current and proposed soil-crop management techniques as they relate to Great Plains dry-matter production.

A cooperative study is currently in progress in the Great Plains Systems Research Unit to simulate the response of wheat and range dry-matter production to changes in climate during drought cycles. We are using geostatistical techniques in conjunction with GIS and model sensitivity analyses to identify appropriate sets of input data for our simulation runs. The objective is to model wheat and range production in the entire Great Plains to at least the county level of resolution, but still restrict the number of required computer runs to a manageable level. We are using historical yield and production information to validate our models prior to making projections. We will then study various drought scenarios taken from the historical record dating back to the early 1900's and perhaps to 1700. Current soil-crop management techniques such as wheat-fallow, no till, and crop rotations will be examined relative to these drought cycles. Various combinations of proposed techniques will be tried in an attempt to identify methods that show promise during drought.

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History and Integration of Wildlife in Great Plains Agriculture

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ABSTRACT

Wildlife populations have been altered on the Great Plains because of agricultural development and human settlement. Changes resulted in positive and negative outcomes. Species became extinct, increased their distribution, were introduced, were overexploited, and were regulated by human actions. Viable numbers of wildlife are currently supported on predominantly private lands and waters without proactive management plans. Huntable and watchable wildlife create demands for recreational opportunities on private lands and waters and those demands are not fully appreciated or supplied by landowners. The challenge is to integrate wildlife and recreation into management of agricultural and range lands so wildlife populations will be enhanced and users will be encouraged.

INTRODUCTION

Wildlife populations on the Great Plains have changed temporally, spatially, and numerically as geologic time altered environments. Wildlife populations will continue to fluctuate over geologic time, but modern human presence has accelerated and exacerbated the process through sheer population expansion and activities associated with food and fiber production. The Great Plains have not experienced rapid human population growth, but agriculture and grazing have made significant impacts on wildlife habitats and populations. Atwood et al. (1971) provided an excellent overview of geological history and how agricultural land-use affected wildlife resources. The purpose of this paper is to review the historical and recent perspectives on changes of wildlife populations and the human-related causes in modern times. Finally, the realities of living with wildlife and the potential recreational values derived from them by agriculturalists and their clients will be explored.

A summary of key points follow concerning how the Great Plains have changed and how I would recommend that they continue to change:

PAST

- From tropics to ice to temperate climates
- From dinosaurs to bison to pheasants
- From hunter/gatherers to corporate farmers

FUTURE

- From wildlife abusers to wildlife users
- From environment takers to environment savers
- From recreation haters to recreation makers
- From single resource minded to multi-resource grounded

HISTORICAL PERSPECTIVES

Stegosaurus and other dinosaurs roamed the Great Plains millions of years ago. Then during the Pleistocene Epoch, 2,500,000 to 10,000 years ago, an influx of wildlife came from the ice and land bridge between Siberia and Alaska and from the volcano-formed tropical land bridge at the Isthmus of Panama. Immigrant wildlife met and interacted with the North American natives. From the north came sabertooth cats, long-horned bison, mammoths, cave bear, dire wolves and an assortment of animals we know better including musk oxen and caribou. From the south came porcupine and armadillo. They met natives such as horses and cougars (Borland 1975).

Borland (1975) emphasized that bison swarmed the grasslands and woodlands and deer were in every thicket. Moose and elk were on the flatlands and thin woodlands. "Beaver, some as big as bears, swarmed in the streams." Birds, fish, and insects filled more of the earth's niches.

Borland (1975) reported that humans also followed the bridges and herds into North America. By the end of the Ice Age (about 12,000 years ago) the human population was estimated at no more than one million. It was doubtful that a maximum of 250,000 male hunters could have hunted the vast herds and species to their eventual extinction. But, extinction resulted at the end of the Pleistocene. Animal varieties and numbers have never been the same. Pronghorn antelope are one of the few living links to the Pleistocene Epoch and a symbol of the Great Plains.

In Europe and other parts of the world, our ancestors began taking what they wanted from the earth sooner than on the Great Plains. European forests were felled, rivers were fouled, minerals were mined, and wildlife were exploited (Borland 1975). New lands were explored and settled, in the interest of existence, civilization, and progress. Natural resources were necessary to bolster political desires and to fulfill an ever increasing demand for goods. These lessons from our homelands may help us to learn the fate for lands and waters of the Great Plains unless we take steps to avoid or mitigate the losses.

SETTLING THE GREAT PLAINS

The Great Plains were settled by Europeans from east to west and south to north. Spanish, French, German, Polish, and English were a few of the nationalities that mixed with the American Indian remnants from the Pleistocene. Spanish explorers reported white bears (grizzlies) following the bison and barking squirrels (prairie dogs) (Borland 1975) that likely caused problems for their horses and cattle. French trappers removed beaver from streams and led the way to westward expansion.

European immigrants found new soils to till along rivers and bottomlands. Settlements were established and native plains were conquered by removing competing wildlife (notably predators and large ungulates) and by introducing new grazers, vegetation, and buildings. Cows replaced bison, pheasants replaced prairie chickens. Pronghorn antelope were condemned and tolerated in numbers below the environmental carrying capacity. Potholes and playa lakes were drained and native grasses were grazed by livestock, mowed for hay, or plowed to make way for agriculture. Meanwhile, wildlife suffered.

Agriculture and settlement also helped many species of wildlife. Pronghorn antelope and Canada geese had a nutritious winter diet provided by early-growing winter wheat. White-tailed deer, mule deer, and bobwhite found corn lands good for feeding if located adjacent to river and stream courses. Field sparrows, meadowlarks, killdeer, cottontails, and prairie deermice extended their range. Prairie grouse benefitted by having crops for food, but when acres of crops increased, populations of native grouse were replaced or displaced by introduced pheasants from the orient and gray partridge from Europe. Introduced English sparrows and starlings used buildings and holes in trees previously inhabited by native species. They fed on crops and became pests.

Trees and shelterbelts were planted to protect farmsteads and cities from wind on the predominantly treeless great plains. Songbirds, raptors, deer, eastern fox squirrels, rabbits and raccoons found new homes.

Dug-outs and windmill tanks for watering cattle. water storage reservoirs, irrigation canals and ditches, and water taps for the "greening" of urban lawns and gardens allowed water to be put to new uses. Wildlife used the new fields, forests and water sources for food, shelter and to rest during migrations.

ENVIRONMENTAL COSTS FROM AGRICULTURAL PRODUCTION

The quest for greater crop yields and more efficiency was successful, but the results were not all positive for agriculture or wildlife. Surpluses were created, profits decreased, and soil and water erosion became problems as lands and waters were used more intensively. Farmers created bigger fields, farmed roadsides, and converted some rangelands into marginal cropland. They stopped leaving waste grains, weed patches, fence rows and shelterbelts. Herbicides, pesticides, and fertilizers were used routinely to bolster crop production, but they reduced the diversity of plants. insects, and larger wildlife communities. Deep water wells and sprinklers led to fewer ditches, more crop yields, and less water in the underground aquifers. Questions arose about the future of deep wells and agriculture. Trees that grew along ditches, canals, and natural water courses were cut down to reduce water loss from transpiration and growth of the plants. Some waterways were lined with concrete to stop water loss. Large water impoundments within river and stream courses changed riparian ecosystems by reducing water flow patterns and intensity. Regeneration of floodplain forests decreased. Riparian zones became more narrow. Cattle contributed to erosion and removed shrubs and trees from streamside banks. Wildlife were affected.

A WILDLIFE-BALANCE SHEET

Bison and grizzlies are extinct from the plains. Sixty species of mammal. bird, fish, reptile, amphibian, crustacean, and plant from the Great Plains are listed on the federal list of endangered species (Anderson 1984).

Ducks are finding fewer undisturbed grasslands and potholes to nest. Water areas to rear their broods are decreasing rapidly and duck production is an international concern. Perhaps 45,000 acres (Stewart 1975) to 450,000 acres (Chandler 1988) of wetlands are drained per year. Only half of the nation's original wetlands remain according to the U.S. Fish and Wildlife Service (Chandler 1988). During the drought of 1988, an estimated 50% of existing wetlands dried up on the northern Great Plains.

A survey of 14 midwestern states by Farris and Cole (1981) between 1958 and 1978 found that pheasants declined an average of 66%, cottontail rabbits 55%, and bobwhite quail 48%. Selected grassland songbirds in Illinois declined over 90% in the similar period (Graber and Graber 1983). In Iowa, 17 species of birds have disappeared as nesters since the time of settlement and at least 29 species have declined to the point that their breeding is in jeopardy (Dinsmore 1981). Choate (1987) reported on an unpublished M.S. thesis by Carter (1939) that summarized the history of mammals in western Kansas from 1840 through 1939. Data were gathered by interviewing early residents. Of the 21 species evaluated, 11 decreased, 3 increased. 6 experienced increases and decreases over time and are found in good numbers today. and 1 species had an unexplained history. Humans were responsible for most of those changes.

INTEGRATING WILDLIFE AND RECREATION INTO FARM MANAGEMENT

Sweeping changes were needed in agriculture to curb surpluses and to improve soil and water resources. The Food Security Act of 1985 provided for numerous conservation measures intended primarily for prevention and abatement of soil and water erosion. The measures could also benefit wildlife. For the first time in the 54-year history of federal farm legislation, farmers could be denied subsidy payments if they did not comply with conservation and management requirements (Chandler 1988).

Unfortunately, but realistically, if wildlife are not beneficial, farmers can select conservation practices that are of little or marginal value to wildlife. For wildlife to benefit, they must be integrated into the plans and management practices of landowners.

Not all farmland can be expected to be managed for desirable wildlife habitat. Food and fiber production are necessary. However, a new interest in practical land and water stewardship that includes wildlife is also necessary. Wildlife and recreation should become integrated into agricultural plans whenever possible. By all means we should avoid negative impacts on wildlife from commission or omission.

One way to avoid negative effects on wildlife from agriculture is to avoid unnecessary changes to land and water and to preserve natural ecological processes where possible. That includes not subsidizing reservoirs for agricultural production in one part of a state when another region is using subsidies to curb agricultural productivity. Shelterbelts should not be removed on one property while they are being planted on another. It means that homes should not be built on prime farm land causing marginal lands to be forced into production. Herbicides, pesticides, and fertilizers should be used with consideration of proper application. crop rotations, companion crops, market demands, and consequences of their use on non-crop environments.

DIRECT BENEFITS FROM WILDLIFE

Wildlife will also benefit when landowners recognize direct values from the existence of animals and the persons who wish to enjoy them by recreating on private rural lands. Wildlife would not be treated as pests if they were valuable to landowners. Recreationists would not be denied access if their presence met the objectives of landowners.

The demand for private open spaces and the wildlife and recreation they produce will be ever increasing. The commodity value will increase in proportion to its quality and scarcity. At this time, public opportunities for wildlife experiences are insufficient to meet demand in the Great Plains. The logical conclusion is for landowners to diversify their objectives to include wildlife production and recreational use. The alternatives are all less pleasant for the landowners. One, they can bear the unpleasant pressure of wildlife and recreationists on their properties until the problems can be fenced out for good. Two, the growing human population may eventually use legislation to gain access rights onto private land as is the case in parts of Europe (our homeland with greater congestion and a greater history of solving similar problems). Third, the public may lose interest in fighting the battle for wildlife and land that they have no stake in and give up the outdoor and conservation spirit altogether. That alternative would not benefit anyone. Living on a land that is divided is no alternative. Having an environment without wildlife is no alternative. Having land without a stewardship ethic for the benefits of present and future generations is not being responsible.

Agriculture, wildlife, and recreationists can become closer partners. Reservoirs can still be built, but needs for wildlife and users should be included actively in the planning. Perhaps dams constructed outside of natural water channels will enhance wildlife and recreation while still providing water for agriculture. Chemicals may still be valuable, but not for creating commodity surpluses at the expense of wildlife. It is also important to continue research into production techniques that require fewer inputs and enable production in closer relationship to demands.

Hunting has been an important wildlife value and recreational pursuit on private lands. The demand is sure to continue, but perhaps at a lower level per capita. However, if access opportunities on private land continue to be difficult to acquire, hunters will likely substitute other forms of recreation or use other locations for their sport. Landowners could miss useful allies and monetary incentives.

Paying to hunt on private land is most common in the southern Great Plains and least common in the northern states. In the plains of Colorado, it is difficult to find good waterfowl hunting areas that are not being leased or purchased for recreational values. Fee hunting for pheasants and big game is currently practiced on a lesser basis.

Fee hunting for pronghorn antelope is an underused commodity. Demand for licenses to hunt exceeds supply in most states of the Great Plains. In Colorado, about three times more hunters apply for licenses than will get them. The supply of pronghorn is artificially depressed because of negative attitudes of landowners who fear that pronghorn compete with livestock and affect yields of winter wheat. Damages to fences are also a concern. Problems may not be as bad as presumed however. Studies from Colorado State University reported no significant damage to wheat (Liewer 1988) and a willingness of hunters to pay for pronghorn hunting on private land in Colorado (Cronquist 1990). It appears that pronghorn could be encouraged and used as an additional crop from the land.

Other recreation such as farm and ranch vacations, camping, nature and history study, and wildlife watching also are possible activities that are underutilized on private lands and waters. Urban persons see private open space as valuable resources but they may not feel brave enough to seek access. Landowners have left negative impressions on recreationists, just as recreationists have abused their privileges and created poor images for landowners.

In the search for ways to obtain additional lands for wildlife and recreation, landowners and governmental decisionmakers may also look to land zoning, easements, tax breaks, cooperatives, leases, and other partnerships to provide sufficient incentives and compensation. For these programs to succeed, there is a need for strong leadership. This usually means that government takes a more active role. Landowners and private rights are not necessarily harmed and can benefit through debt relief, tax breaks, and management assistance. The flexibility currently appreciated by the private sector is compromised however. At this point in development of lands and populations in the Great Plains, the alternatives with too much governmental intervention seem less practical and valuable. In addition, some of the best management of wildlife and recreation is taking place on private land. Landowners have the ability to make wildlife and recreationists valuable assets in an integrated farm and ranch management program.

CONCLUDING REALITIES OF LAND, WILDLIFE, AND PEOPLE ON THE GREAT PLAINS

In summary, there appears to be eight realities to life on the Great Plains that cannot be avoided. One, wildlife belong to the people of the state and nation and two, the publics will insist that animals are maintained on private land. Three, private landowners will retain their property rights to accept and deny access to their lands. Four, wildlife and recreationists will attempt to use private land and five, many landowners can benefit from demands to provide wildlife and recreational opportunities. Six, if wildlife and recreationists are considered to be assets they will be encouraged and seven, if they are liabilities they will be discouraged. And eight, cooperation is better than conflict.

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Soil and Crop Management as a Driving Variable

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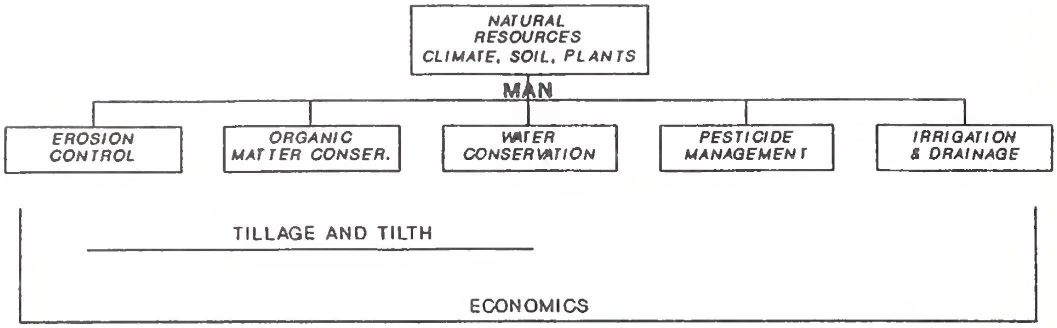
Key terms in the title of this paper are "management" and "driving variable". "Management" of the soil resource is obviously essential for the sustainability of agricultural production everywhere, but especially in the Great Plains. The term "driving variable" has the connotation of control and regulation of other subordinate variables. Historically, "management" has been a "driving variable" in the Great Plains. This paper will attempt to show that management is a control variable and that many other important variables are "driven" by it.

Soils cannot be managed independently of the plants being produced on them and so it is most correct to speak in terms of "soil and crop management". Our definition of management is: Man's intervention into biological systems to foster improved and sustained production of food, fiber and forage. Figure 1 diagrammatically relates man's involvement with the natural resource base of climate, soil and plants to the major areas of management. The manager's goal is to maintain and improve the soil system while enhancing economic crop production (Peterson 1979).



Man's intervention into biological systems to foster improved and sustained production of food, fiber and forage.

Figure 1. Diagram showing relation of human involvment with the natural resource base.

Soil and other environmental degradation has occurred in the past when man used land for farming or grazing purposes with a "hands off" approach to management. Erosion has been accelerated by almost all of man's practices with subsequent losses of N, P, soil organic matter, and even rooting zone depth. Degradation has occurred on range lands as well as cultivated land. A fundamental aspect that must always be emphasized is that management has cumulative effects that are not readily apparent and are not easy to reverse. Papers by Anderson and Peterson (1973), Peterson and Vetter (1971), Herron and Erhart (1965) and Edwards, et al. (1973) provide evidence, both positive and negative, regarding these cumulative effects.

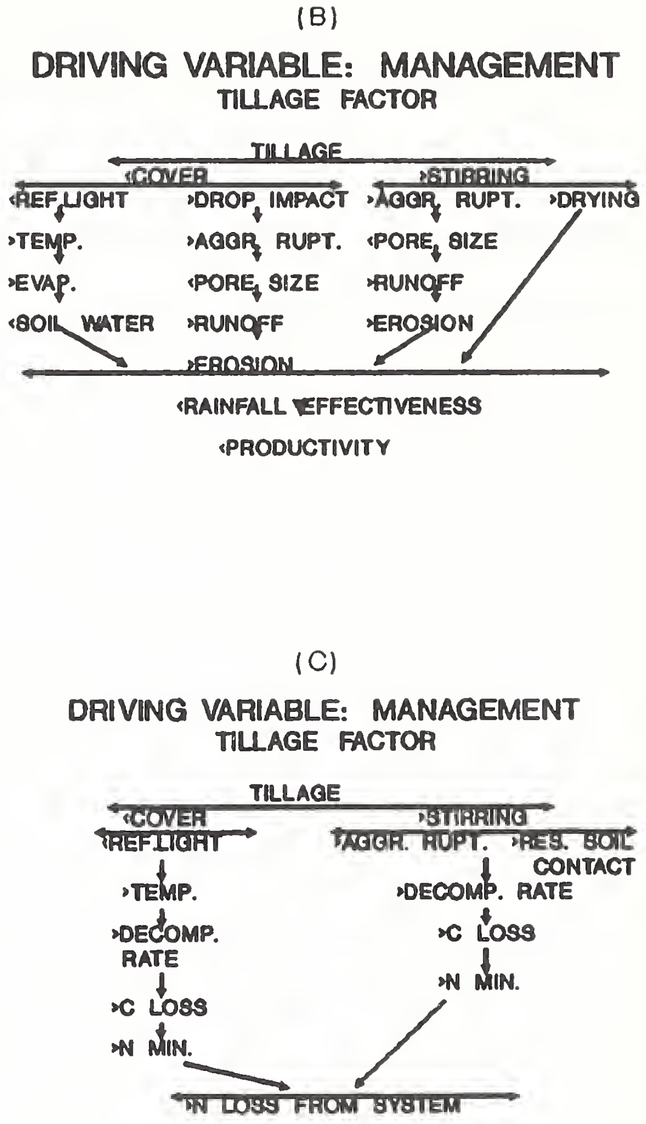
Plant productivity in the Great Plains has two major limitations: (1) Water supply and (2) available N supply. Imagine the Great Plains prior to the arrival of modern man under "natural management" where plant productivity was basically in balance with the water and N supplies. Plant productivity was relatively low and stable year to year and varied according to variability in annual rainfall and distribution of that rainfall. Nitrogen cycled within the system relatively uniformly and was subject to the same factors that controlled productivity. When farmers and ranchers imposed grazing and cultivation schemes on the area the entire biological system was affected; most of the time adversely. Maximal change occurred in farmed systems when the moldboard plow was used for primary tillage in seedbed preparation. Changes brought about by the management switch from the original grass vegetation to the cultivated system are displayed chronologically in Figure 2(A). Consider the drastic difference between natural management and early-day farmer imposed management. Therefore, it is not surprising that many problems arose as this change occurred.

(A)

MANAGEMENT TIME LINE

TILLAGE EFFECTS

1880	1930	1980	2030
Grass Cover (No Till)	Bare Soil (Max Till)	Partial Cover (Less Till)	Residue Cover (Min Till)
SYSTEM CHANGES			
Min. Evap.	Max. Evap.	Reduced Evap.	?
Max. Aggr.	Min. Aggr.	Improved Aggr.	?
Min. Runoff	Max. Runoff	Reduced Runoff	?
Max. Infil.	Min. Infil.	Reduced Infil.	?
Max. O.M.	Decl. O.M.	Min. O.M.	?



(B)

DRIVING VARIABLE: MANAGEMENT
TILLAGE FACTOR

(C)

DRIVING VARIABLE: MANAGEMENT
TILLAGE FACTOR

Figure 2. Tillage management as a driving variable. (A) = Time line; (B) = Physical; (C) = C & N.

As farmers imposed their highly tilled management systems on the "natural system" water use efficiency decreased because tillage increased the evaporation portion of the evapotranspiration system. Two mechanisms account for this increase:

- Cover, a deterrent to evaporation (Bouzerzour 1983), was destroyed, and
- Each tillage operation restarted Stage I evaporation by bringing moist soil to the surface.

Erosion by wind and water was increased as both forces were able to directly impact the soil surface. Raindrop impact on soil surfaces was larger and hence destruction of aggregates increased which in turn decreased macropore space at the soil surface. Consequently infiltration decreased and runoff increased (Fenster et al. 1977). In short, the opportunity for water storage was decreased and the potential productivity decreased. Figure 2(B) shows the impacts of cover removal and soil stirring on each of the processes and how they relate to each other. Continued cultivation magnified these changes. Farmers eventually adopted summer fallowing in the semiarid climatic zones to reduce the risk of crop failure and to improve economic stability (Greb 1979).

Nitrogen, the second most limiting factor, was also adversely affected by the change to tilled systems. Nitrogen loss as a function of history of cultivation is a fact that has been well documented by Jenny (1933) and Peterson and Vetter (1971). This loss resulted from the change to a crop removal system managed with small amounts of cover and highly stirred. Nitrogen mineralization from organic matter and enhanced percolation losses of NO_3-N (Table 1 and Figure 3) (Lamb et al. 1985) were promoted by this change.

Table 1. Nitrogen budget (kg ha^{-1}) in a wheat-fallow rotation as affected by tillage system[1].

Factor	No-Till	Stubble Mulch	Plow
Total N in soil	4050	3720	3580
Total N in sod	4200	4200	4200
Total N change	-150	-480	-620
Grain removal	260	320	280
N unaccounted for by crop	110	-160	-340
Leached NO_3^- > sod	270	250	370

[1] *Experiment E., Lamb et al. 1985. SSSAJ 49:352-356.*

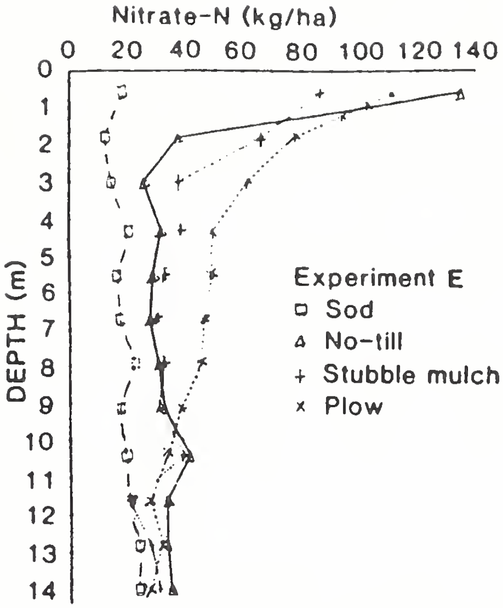


Figure 3. Soil profile nitrate—N distribution as influenced by fallow management (Lamb et al. 1985).

The Dust Bowl days are the ultimate reminder that management has been a primary driving variable in the Great Plains. They were a direct result of man's misunderstanding of the system that he was trying to manage. Development and adoption of "stubble mulch" techniques in the 1940s began to reduce erosion problems and save more water, but did little to reconcile previous losses of organic matter and N. Nitrogen fertilization was not recognized as a necessary input until the early 1970s in much of the Great Plains (Sander and Peterson 1971). To that point in time, release of N from native soil supplies maintained crop production. As this supply was depleted by erosion, crop removal, and leaching, a need for a supplemental N source occurred. Today few acres do not receive N fertilizer as an essential input to stable and economic yield levels.

By the late 1960s substitution of herbicides for some tillage operations began at least on an experimental basis. This allowed even less stirring and greatly enhanced water conservation, especially in areas that received much of their precipitation as relatively frequent small shower events. Bond and Willis (1969) showed the effects of residue on evaporation and why mulching was so potentially important in the Great Plains. Since that time Greb et al. (1967), Unger (1978), Smika and Wicks (1968), Fenster and Peterson (1979) all have shown the great value of residue cover to water conservation. Residue cover coupled with little to no soil disturbance improved water conservation in wheat-fallow rotations to the point where fallow efficiencies were maximized. The soil could not hold all of the water being saved and deep percolation increased. The wheat- fallow rotation could no longer make efficient use of the water because soil storage capacity was not large enough to hold it. In the Northern Great Plains this increased efficiency has created saline seeps (Halvorson and Black 1974) in some instances. To effectively use the water conserved by these techniques rotations with more crop years and fewer summer-fallow years have been adopted. Production of summer crops like grain sorghum or corn following wheat is a reality. Future developments may permit the total elimination of a summer fallow period in some parts of the Great Plains.

Figure 2(A) also predicts future changes that may result from management systems where surface residues are maintained and soil stirring is decreased. Weed control in crop and non-crop parts of the rotation is vital to improved water conservation and herbicide substitution for tillage is a key factor in the new systems. Note that organic matter content may increase and that evaporation is reduced along with runoff. Greb (1979) described the historic changes in soil water management which improved water-use efficiency (WUE), and how these accompanied progressive changes to management practices with more cover and less tillage. The combined effects of improved surface aggregation on water infiltration rates and reduced runoff accompanied by less evaporation have had a positive impact on total productivity. Modern experience has shown that rotations with more crops and less fallow can now be used, which result in even greater increases in precipitation use efficiency by crops over time.

The two primary parts of management in the Great Plains are residue maintenance and tillage intensity. The driving variable, management, has major effects through the amount and type of tillage use. As it is altered it has a large impact on residue cover and soil water storage, thereby affecting many processes in the soil as well as long term sustainability of agriculture in the Great Plains.

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Economic Issues Related to Sustainable Agricultural Systems in the Great Plains

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SUSTAINABLE SYSTEMS CONCEPTS

Bunce (1941) defined and Heady (1952, Chapter 26) conceptualized what can serve as a starting point for a working definition of a sustainable agricultural system. With respect to land Bunce states "Conservation of agricultural land (sustainable agriculture) appears to mean the maintenance of the fund of resources and present level of productivity of the soil, assuming a given state of the arts", (Bunce 1941, p. 7). Heady's interpretation of Bunce's definition introduces the concept of a production function which expresses the level of output at a point in time from, say, an acre of land planted to a crop as it responds to varied levels of input application, Figure 1; or, $Y = f(X_1/X_2 \ldots X_n)$, where Y is output, X_1 is a variable input and $X_2 \ldots X_n$ are inputs or resources which are fixed. A different response function, OA, OB, OC, etc. is associated with each level at which $X_2 \ldots X_n$ are fixed. Suppose the original input of resources (labor, capital in the form of a complement of machinery and equipment, tillage practices, seed, fuel, fertilizer, etc.) is OX_2. We are not necessarily concerned with the sustainability of the system if we move from OX_2 to OX_1. Movements along the function OA, as between OX_2 and OX_1, may occur over time in response to changes in resource-product price relationships.

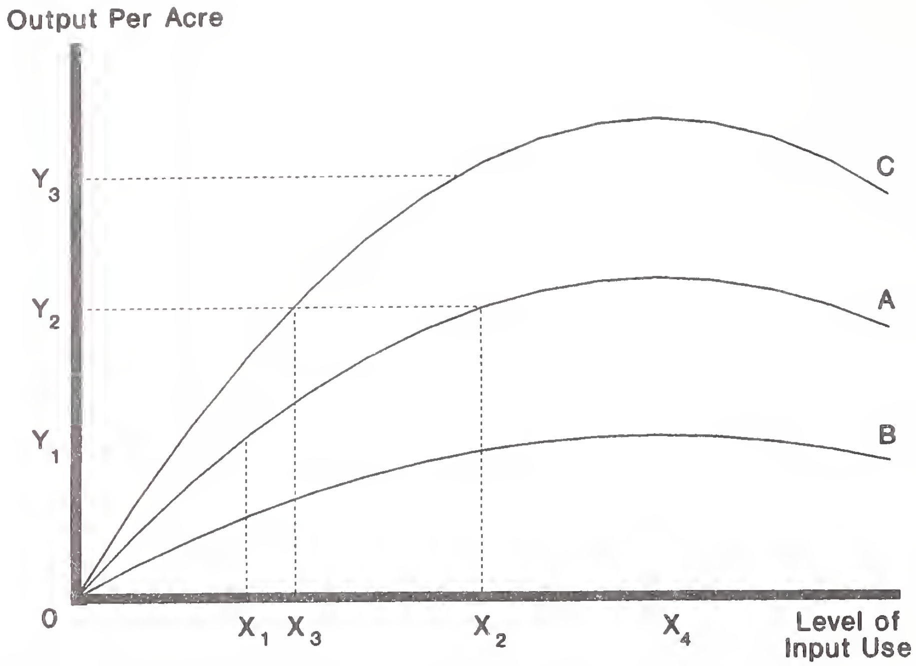

Figure 1. Production functions expressing output per acre responding to varied levels of input intensity.

Bunce's definition has to do with preventing a fall from production function OA to function OB while maintaining resource use at level OX_2. If, over time, we can maintain OY_2 only by adding to the bundle of resources OX_2; or, by increasing the level at which $X_2...X_n$ are fixed, we have a system which is not sustainable. While OX_2 includes chemical fertilization, we may be mining some nutrients inherent in the soil over time so that OY_2 can be maintained only by increasing the application of chemical fertilizers. To be sustainable, the system must at least let us remain on OA through time with the given state-of-the-art. As prices change between years, variation may occur as to where on OA it is most profitable to operate.

The quest for sustainable agricultural systems goes beyond the prevention of a fall in the production function for a given state-of-the-art. It also seeks to develop new technologies which result in an upward shift of the function, such as from OA to OC (Heady 1952, Chapter 27). Such an innovation can be either input saving, input using or output increasing, or some combination of either input saving or input using with output increasing. In the aggregate, all technological advances are either output increasing from a given set of resources or input saving for a given level of output. Likely, sustainable agriculture technologies would seek to be input-saving. For example, practices such as phenologically timed input applications or development of disease-resistent varieties could maintain or increase yields while reducing use of selected inputs and costs.

Reduced levels of chemical and purchased input use are not the immediate goals of sustainable agriculture systems; rather, the goal is that of environmental protection. Anderson (1988) states..."sustainable agriculture...is a production system that is biologically capable of being maintained over long periods of time...the system must be economically attainable and ecologically sound so as to not degrade the environment in a significant way...the system will maintain the productivity of the land resource without degrading other natural resources". While definitions are boring to most of us, because of the plethora of concepts and terms as well as advocates and reactionaries, it is well to begin with a working definition. From such a definition we can move quickly to the scope of economic issues related to the topic of sustainable agricultural systems.

First, it should be mentioned that the issue of the optimal allocation of a stock resource over time, such as the mining of groundwater from the Ogallala aquifer, will not be addressed here. Like Rodale's regenerative agriculture concept (Rodale 1988), we will focus on the use of resources which are of a flow nature. With Anderson's view, several agricultural resource use practices are clearly excluded from the set of sustainable practices. Continuation of erosion-inducing tillage practices and use of chemicals to control pests and provide plant nutrients which result in damage to the environment are practices which are not a part of a sustainable system. If input use OX_2 along OA causes damage to the environment, a movement to OX_1 may be necessary to provide a sustainable system. Or, biotechnologies may result in a shift from OA to OC which could increase the ratio of output to input use. As research attention is focused toward developing practices which are biologically and ecologically sustainable, they must also meet the test of being economically sound. To be economic and sustainable, three groups of issues are involved:

- Is the sustainable agriculture financially feasible for the farmer? To be adopted, any technical change must increase the expected profits of the firm, at least temporarily. It must be quickly added, this involves consideration of both how net returns are affected as well as the variability (risk) of net returns. Some technologies may increase expected profits through a reduction in the discount for risk.
- The second set of issues has to do with how well market prices reflect the true costs and benefits of agricultural inputs, production technologies, and products. Consideration of this issue also involves how sustainable systems can be implemented. Sustainable technologies may result from discovery of improved technologies which increase profit per acre and the net income of the farmer. Such are happy circumstances. But it is also possible, and perhaps more likely, that what is deemed to be a sustainable system may be less profitable to a farmer than a presently used system of production which is not sustainable. Under such circumstances society may decide to impose limitations on how farmers may use their resources. This has been accomplished by trying to internalize to the farmers some of the costs which society views as deleterious to the environment. If chemical use pollutes water, the costs of cleaning up the water could be incorporated in the price of the chemical. Alternatively, controls can be imposed by fiat; chemicals have been banned and more recently, certain farming practices have been discouraged. Or, in the extreme, legal litigation may be brought against a polluter and fines or damages assessed.

  On the other hand, certain production technologies may result in an improvement in the natural resource base. Soil structure and tilth may improve, noxious weed eliminated on grazing lands and naturally occurring erosion may be checked. While these benefits may not be fully realized by the current operator, the benefits to society should also be counted.

- The third set of economic issues have to do with how the sustainable systems affect the structure of agriculture. The concern here is whether or not the sustainable systems are scale neutral among farms (is it easier for the technologies to be employed on large farms or small farms) and how the widespread adoption of sustainable systems affect the regional interdependence and the infastructure serving agriculture.

FINANCIAL FEASIBILITY

The first-listed principle of the USDA initiative for Low Input/Sustainable Agriculture (LISA) is "if it isn't profitable, it isn't sustainable" (Madden 1988). Referring again to Figure 1, the economic analysis is concerned with whether a low level of input application such as at OX_1, is more or less profitable than conventional or higher levels of input use as at OX_2 (Holt 1988). With adequate data, the economist can indicate where along a curve such as OA is the most profitable (i.e., economically optimal).

Several economic studies have been completed of alternative agricultural systems (Goldstein and Young 1987, Williams et al. 1987, Macartney 1987, Dobbs et al. 1988, Madden and Dobbs 1988). The analyses involve per acre cost and return estimates for crops or rotations of crops under alternative systems. Even under the best of circumstances the appropriate comparisons are difficult to obtain. There may be instances under which environmentally damaging practices result from poor management or ignorance: however, Macartney found more intensive farming practices are practiced by the more educated farmers in the Canadian prairies. Dobbs compared the results of experimental trials involving conventional with two alternative cropping systems. Since the experiment lasted only two years, yields were "normalized". Sensitivity analyses revealed the extent to which conclusions reached were affected by yields, prices and government farm programs.

Several of these studies have suggested the importance of risk to selection of farming systems; risk may either increase or decrease with alternative systems of production (Helmers et al. 1986, Williams et al. 1987, Goldstein and Young 1987). Likely, routine applications of pesticides occurs, in part, because risk is reduced. On the other hand, farmers may find low input systems to be preferable to conventional systems because they reduce financial risk, even if expected net returns in the low input systems are less. The crop diversification associated with many sustainable systems can also result in a reduction of between year variability of income (Heady 1952, Chapter 17).

Many of the economic analyses consider the extent to which tillage operations can be substituted for chemicals. Figure 2 presents the economists' notions of substitution possibilities between different types of inputs. Reduced tillage practices favor operations at point A, chemical herbicides are used in place of additional tillage operations. Many of the sustainable agriculture experiments are now considering how well tillage operations can replace chemicals; movement towards point B is the desired result.

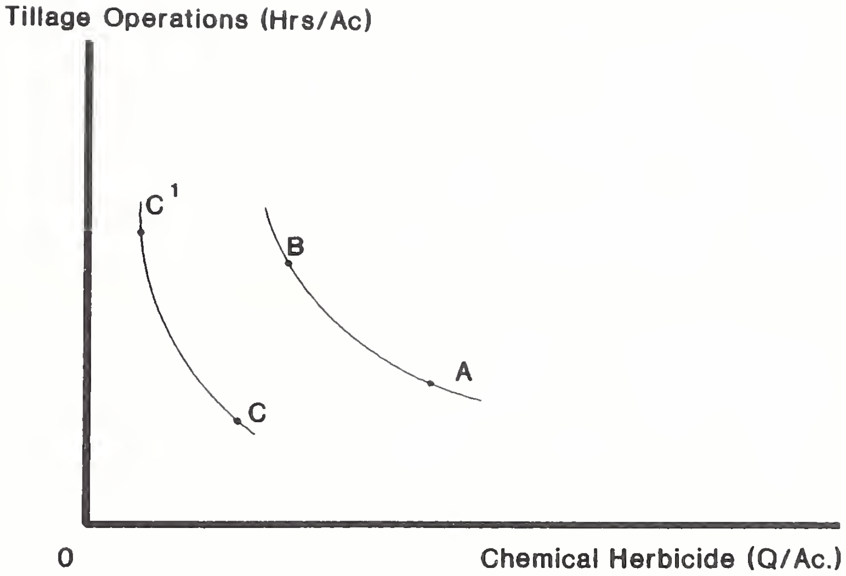

Figure 2. Substitution possibilities between chemical use and tillage operations.

Suppose we are operating at a point such as A and that this is the combination of tillage practices and chemicals which is consistent with the relative market prices or costs of tillage operations and chemical applications. If the level of chemical use at A is found to be deleterious to the environment and the adverse effects of chemical use are included as costs as part of the price of chemicals, a substitution toward more tillage-intensive practices such as point B would result. Points A and B are on the same isoquant which reflects input combinations which result in an equal level of production. But, as the price of chemicals increases relative to tillage operations, they also increase relative to output prices. Consequently, output will be reduced to a lower level, a level which is depicted by isoquant II. The new economic optimum along II may or may not result in a net substitution of tillage practices for chemicals. If the two types of inputs are economic complements, less of both types of inputs will be used at the new equilibrium; such as at point C. However, if the inputs are economic substitutes, the net effect will be a substitution of tillage inputs for chemicals at the new economically optimal combination of inputs on II, as shown with C^1.

All changes in technology have the effect of changing the rate at which inputs substitute for each other. Because of this, technologies have been characterized as being either labor saving or land saving. As to which is desired depends on the relative prices of the resources involved and, vis a vis sustainable agriculture, the environmental impacts.

Perhaps some of the more successful efforts toward developing sustainable agricultural systems have been in the area of integrated pest management. For many of the integrated pest management systems, additional information (and perhaps labor and management) is substituted for chemicals (King et al. 1986). That is, routine, preventative applications of chemical pesticides such as at point A in Figure 3 would be avoided by having more information about impending pest populations. The added information would permit a reduced application of the chemicals over time, such as at point B. Both A and B are on the same isoquant; production levels are equal at all points on the isoquant. The least cost point of operation occurs where the ratio of the marginal product of information relative to the price of information is equal to the ratio of the marginal product of pesticides relative to the price of pesticides. Or, even if the least cost point occurs somewhere on the continuum between A and B, partial budgeting analyses can indicate whether or not B is a lower cost point of operation than A.

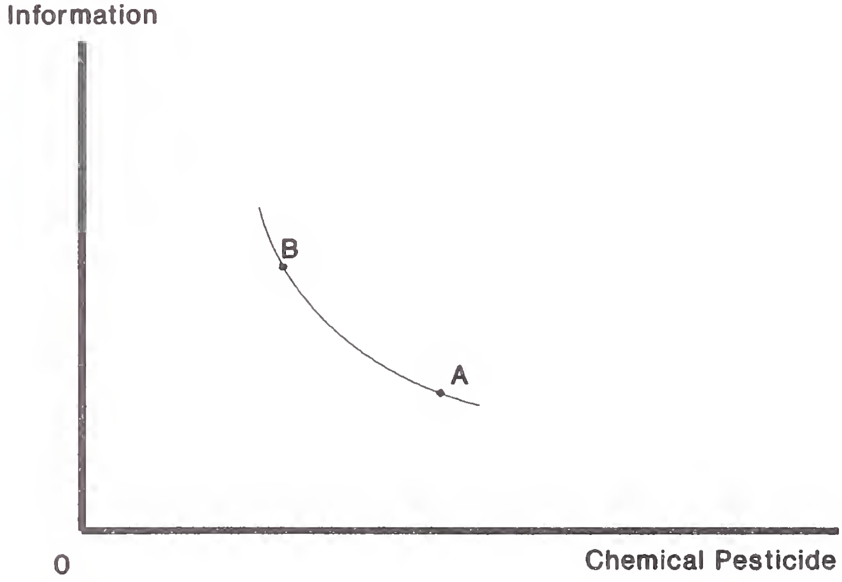

Figure 3. Isoquant showing possibilities to substitute information for chemical use.

MARKET FAILURES

The concept of optimality has been a point of debate among economists and biological sciences of agriculture. For example, following von Liebig's "law of the minimum", agronomists have tended to define the optimal amount of fertilizer as the amount which ensures that that nutrient will not limit production. Applying fertilizer to achieve the maximum yield per acre (OX_4 along OA resulting in OY_3 of production in Figure 1) has been challenged by economists. Equipped with marginal analysis, economists advance the concept of optimizing with respect to input costs rather than an acre of land. Fertilizer would be applied only to the point at which the added value of product resulting from the fertilizer application stops being greater than the added cost of the fertilizer. Thus, if the input (fertilizer) has any value, the economically optimal level will always occur at a level to the left of OX_3.

Suppose OX_2 is the profit maximizing level of use for a fertilizer nutrient used to produce a monoculture of corn. Two problems could arise: (1) continuous cropping of a row crop may result in topsoil losses so severe that OA can be maintained over time only by gradually increasing the amount of fertilizer applied, or (2) the level of fertilizer applied at OX_2, either because of application techniques or soil conditions, results in a certain amount of the nutrient to be leached to pollute groundwater. Clearly, both are not sustainable systems. In the first case, the costs of topsoil losses are not taken into account and in the second instance, water quality is not protected. Neither condition is possible within Anderson's definition of a sustainable system.

Both deleterious soil loss and groundwater pollution are examples of negative externalities. The market system used to allocate resources in our society does not serve us very well in instances such as these. The present value of future production from the eroded topsoil is discounted too greatly relative to current use values; near term exploitation is the result. Groundwater pollution occurs because of the (a) disassociation between polluters and the users of the resource or (b) the impossibility of one individual to protect the quality of a common resource ("the tragedy of the commons"). In both cases, third parties who are affected by the resource use decisions are not represented in the market. Huszar (1988), for example, estimates the third party costs associated with soil erosion.

Economists consider two options to remedy negative externalities: taxes and controls. Suppose that the continuous corn cropping system results in a topsoil loss of 20 tons per acre each year. The soil loss requires the farmer to apply more fertilizer per acre each year to maintain a constant yield and the topsoil loss may be a source of chemical and sediment pollution to surface water sources. To encourage less erosive farming practices, society could place a tax on soil loss, say, one dollar ($1.00) per ton per acre per year. The cost of producing continuous corn would increase by $20.00 per acre relative to costs of a cropping system which includes a rotation of less erosive legume and small grain crops. Thus, by taxing resource degradation, society promotes more desirable resource use practices.

Alternatively, society may impose less erosive cropping systems on the farmer such as is expected from the Conservation Compliance provisions of the 1985 Food Security Act. A cropping system cannot be used if it results in excessive soil losses; the penalty for continuing erosive practices is the loss of farm program benefits which may easily exceed $20.00 acre^{-1}. The tax on soil loss or the forfeiture of subsidies internalizes the cost of resource- exploitative practices; the social costs of polluted streams becomes associated with the cropping practices which lead to the pollution.

In the case of excessive nitrogen polluting groundwater, the effects of a tax can be shown with hypothetical fertilizer demand curve as in Figure 4. Suppose the profit maximizing level of nitrogen associated with price P_1 is ON_1 along demand curve DD. This amount of N results in groundwater pollution; a tax of P_2-P_1 increases the price to P_2 and reduces the quantity demanded to ON_2. The State of Iowa, for example, recently imposed a tax on nitrogen fertilizer. Ideally, the tax would limit the use of N to the amount which is fully utilized by the crop. It should be noted, a tax to limit the excessive use of a polluting input can only be effective if the quantity demanded for the input is relatively sensitive to price changes. If the demand curve DD is more steep, such as D^1D^1 reflecting a limited response of quantity used to changes in price, a tax-induced price increase will only reduce demand from N_1 to N_3. Unfortunately, most studies estimating the elasticity of demand for inputs used in agricultural production reveal the demands for these inputs to be relatively inelastic.

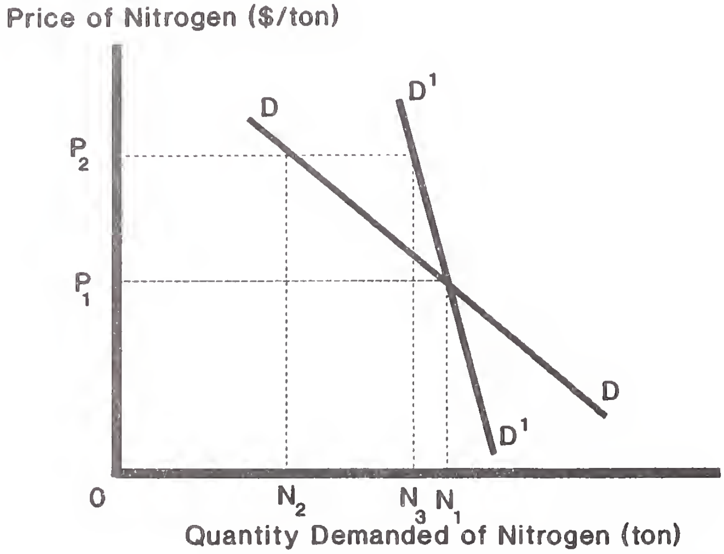

Figure 4. Potential for price adjustments to control input use depends on the shape of the demand curve.

Alternatively, the reduced level of nitrogen use could be administratively controlled. Regulations would permit only ON_2 of nitrogen to be used on a certain crop. Production is reduced below the profit maximizing level but the social costs of excessive nitrogen use are avoided. It should be mentioned, however, that regulations short of a complete banning of a substance are very costly to enforce.

STRUCTURE OF AGRICULTURE

Many of the low input/sustainable agricultural systems being studied represent a more extensive use of the land (with respect to purchased inputs) than presently is practiced. Reduced purchased input levels may be associated with lower profits per acre. Farmers will have to choose between accepting lower levels of income or expanding the size of their operations by adding acres of land.

On the other hand, some sustainable systems tend to substitute higher levels of management for purchased input use and substitute labor and machine operations or increased information for chemical inputs. More labor and management intensive inputs favor smaller sized farms. In fact, the intensity of input applications may increase; labor, management and other farm-supplied inputs may be substituted for purchased inputs. Economists must research the implications of sustainable agricultural technologies on the size structure of farming.

Adoption of sustainable systems across the U.S. can also impact the spatial structure of agriculture and the regional patterns of specialization. More legumes in rotations would likely stimulate the reintroduction of livestock on many specialized cash grain farms. Reduced monoculture will limit the need for interregional flows of commodities. Certain regions may gain relative to others in their ability to supply commodities at lower costs. These implications to the spatial structure of U.S. agriculture are also important topics for research.

Most sustainable systems alter input use patterns on farms; non- purchased inputs are often substituted for purchased inputs. Areas which presently practice monoculture will likely have more product diversity. The existing input supply and product market institutions will have to adjust to the needs of the new systems. These agribusiness firms have already been disappearing at an alarming rate. In fact, the economic viability of rural communities is becoming an increasing concern. It is likely that most of the sustainable systems will change the array of goods and services offered by the agribusiness sector. Economic research must also evaluate the effects of sustainable agricultural systems on the viability of the agribusiness sector, especially in the local economy. For this reason it is necessary that another dimension to the notion of a sustainable agricultural system be recognized. A sustainable agricultural system must preserve the infastructure necessary to make any agricultural system possible. The human element of the system must also be considered. The agricultural systems must sustain the people, the infastructure and the communities necessary for the very existence of agriculture.

ORGANIC SYSTEMS

Some proponents of limited input systems move quickly to the thesis that organic farming techniques are the only systems which have long run sustainability. Others see possibilities for organic systems to coexist with chemical using practices; in some instances organic products can be supplied competitively with conventionally produced products. But, part of the success of organic systems will depend on how well the market can be partitioned to serve these organic producers. As standards and grades are established for organic products and groups of consumers are willing to pay additional amounts for guaranteed organically produced products, the market system can easily accommodate differentiated products. Consumer acceptance and willingness to pay studies are needed for the economic evaluation of organic systems (Menkhaus, et al.).

AGGREGATE EFFECTS

The reduced levels of output which are likely to result from limited input/sustainable systems, such as shown in Figures 1 and 2, can be expected to have aggregate implications. Because of the generally observed inelastic demand for agricultural products, a relatively small reduction in supply results in a sizable increase in price. Figure 5 reflects an inelastic demand curve. Lower levels of output would mean the aggregate supply curve could shift to the left, from SS to S^1S^1. A relatively large increase in product prices could occur since the demand curve is relatively insensitive to price changes. Consequently, widespread adoption of limited input systems which result in output reductions could result in upward pressures on farm commodity prices and farm incomes.

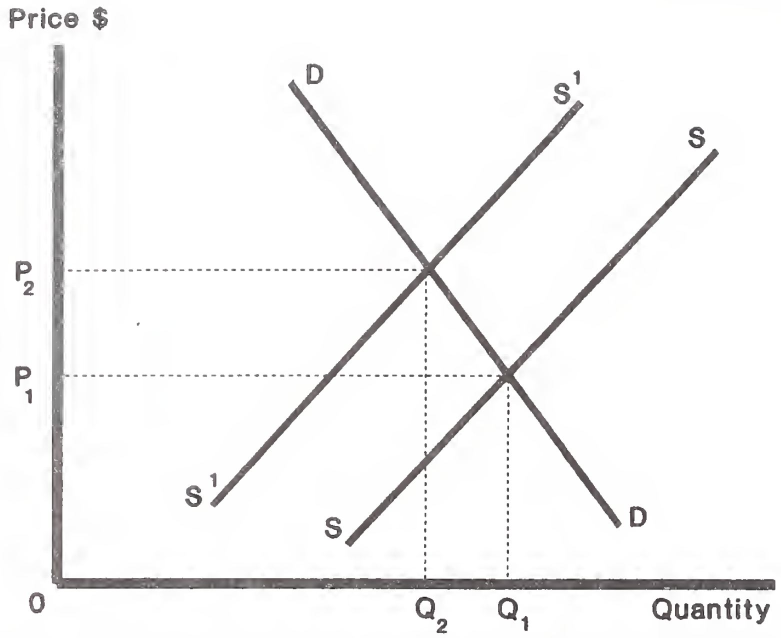

Figure 5. Shifts in the supply curve may mean higher prices for agricultural commodities.

Economists have long observed that agricultural commodity prices and farm incomes could be increased by reducing input use or the output from the agricultural sector. Government land diversion policies are predicated on this notion as have been numerous farm organization action programs. However, the atomistic nature of the farming sector makes it difficult to achieve voluntary action to reduce input use and, hence, output levels, thereby increasing income. Individual producers generally succumb to profit incentives available to them by departing from a group action to restrict supplies. Thus, while it is theoretically possible that widespread adoption of sustainable (and perhaps output reducing) agricultural practices would increase farmer incomes, it is not reasonable to expect it to result from voluntary action on the part of individual farmers.

The distribution of the impacts of sustainable agricultural systems may not be uniform, however. The cost and output adjustment effects for some producers of a given commodity may be small while other producers would be faced with significant adjustments. To the extent that the ease of adapting sustainable agricultural systems differs among regions, the comparative advantage among regions for producing agricultural products or commodities could shift. Some regions might gain in their relative cost advantage in relation to other regions and the spatial structure of U.S. agriculture will change.

On the global scale, it is also necessary to consider the effects of sustainable systems on the ability of our agricultural products to compete in world markets. Here, both product quality standards and supply costs are important. Some environmentally conscious nations may prohibit the importation of commodities with chemical residues, such as the recent barriers which the European Economic Community has implemented for beef imports. On the other hand, other countries may select imports from among the lowest cost suppliers. Each of these international dimensions must be addressed by research.

REQUIRED ECONOMIC ANALYSES

Economic analyses for sustainable agricultural systems will best result from a systems approach to the research and extension of the results. Economists must be involved with the physical and biological systems scientists in the planning and in the conduct of research and in educational programs to agribusiness and producers. *Ex ante* economic analysis of previously conducted research or tangental economic education programs are not likely to provide answers to the questions involved.

Sustainable agricultural systems may or may not be low input. To be sustainable, the system must be capable of being maintained through time without additional inputs, technical change and without damaging the environment, endangering the health of workers or consumers of food, while maintaining a viable agricultural infastructure. Policies or programs to eliminate undesirable (non-sustainable) systems must be able to discern between high-input systems which are sustainable and those which are not sustainable.

Many ongoing practices are not sustainable. It will be fortunate if systems can be found for which costs of production can be reduced more than yields and returns. Likely, however, conflicts between private incentives and social goals will be found to exist. Farmers may have certain environmentally protective practices imposed upon them. Under such circumstances, economic analysis is needed to help identify policy options. assess the incidence of costs and benefits, and evaluate the trade-off between private and public benefits.

The economic analyses needed to evaluate the financial feasibility of sustainable systems include:

1. Enterprise budgeting. partial budget and whole farm analyses of alternative systems. Sensitivity analysis of the alternative systems to changes in costs, yields and exogeneous incentives would be an expected part of this research. These analyses must be conducted over time, space and for the varied commodities and rotations.
2. The systems must also be evaluated for their effects on risk. Since farmers often accept production strategies which have lower expected net returns but also have less variability of returns, risk analyses is needed to complement the budgeting analyses of alternative systems.

Analysis of financial feasibility must be combined with analysis of the economics of effecting change in agricultural systems and the implications of those changes to the agricultural economy. Such analyses include:

3. Given the imperfections of the market and the likelihood that certain sustainable systems will only be adopted with (a) incentives or (b) regulations, economic evaluation must also consider the policy approaches to securing the more socially desirable farming practices will be most effective. The magnitude of the incentives required and the economic impact of the regulations must be considered.

4. Widespread adoption of agricultural systems which affect the supply of products will result in changes in price relationships. The aggregate implications of low input/sustainable systems to the size structure of farms and to regional and national agricultural production levels must be estimated to assess the changes in commodity supplies and regional production and product distribution patterns.
5. To be sustainable the system must also provide a level of economic activity sufficient to sustain the infastructure of the agricultural system. The effects of evolving agricultural production systems on farm size and type, demand for off-farm inputs and product markets, and the viability of regional economies is an important, but to-date neglected, aspect of a sustainable agricultural system.

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Common Sense and Statistics

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INTRODUCTION

I want to begin with observations relative to our business of research. We have an impetus to publish the results of our work. We publish because we want to share our observations with others, or possibly because of the desire for recognition or maybe because it is required to keep our jobs. At the same time, we find we have a shortage of journal space and we have to compete for that space. We also find we are working with more complex systems and estimating smaller parameters with less resources than were available in the past. Technology has improved our abilities to estimate more responses from experimental material but at the same time has increased the costs associated with research. All of these factors have generated a level of discomfort among scientists and administrators because the bottom line is that it is becoming more difficult to accomplish and publish research.

A rather "knee-jerk" response to these difficulties has been the evaluation of research on the basis of the quality of the "statistics" used in the design, implementation and interpretation of the research. While this is seemingly a good criterion, several years of statistical consulting and responding to reviewers comments on sampling, design, analysis and interpretation of research has convinced me that we use common sense less often in the statistical aspects of research. We are convinced through well-intentioned but ill-founded training that there exists a "best" way to sample, design, analyze or interpret a particular experiment. We are so intent on the development of generic algorithms to handle data that we have lost sight of some of the real objectives of what we are doing. It might be argued that there is no such thing as common sense but, defined as "good judgment free from emotional bias and intellectual subtlety," (Gove 1981) it will work for this discussion.

The objective of this presentation is to address some of the challenges in the present research environment particularly with regard to the application of statistics to the research process. The intent is to generate ideas and discussion, not to criticize. A critical evaluation of how we do things, however, will be required. At the end of this presentation your response will probably be "I knew all of that. So what's new?" Everything that I say will probably be familiar to you. I hope that I can convince you to incorporate some of this "old" ideology in how you perform your research, manage research programs, and evaluate other scientists' research.

I was asked to discuss statistics on a philosophical basis but to do this it is helpful to define the context of the application of statistics to the research process. The context, of course, is what we know as the scientific method and this will be a framework for our discussion. We are all familiar with the steps of the research process:

- Make observations to define a problem.
- Observe the system relative to potential solutions.
- Formulate hypotheses.
- Test hypotheses.
- Interpret results and formulate theory.
- Test theory.
- Restate theory to encompass new findings.

RESEARCH PROBLEM DETERMINATION

Definition of the research problem is critical to the whole process of research. It requires a comprehensive understanding of the problem area, communication with clientele, communication with others working in the problem area and familiarity with the literature. It is my concern that the basis for the choice of a research problem is determined by availability of funding or current trends or likelihood of publication. Please do not misunderstand this statement; good research problems will normally have funding and publication potential and will be under study by a number of people. How the choice is made is the real issue. Problems should be identified on the basis of the importance of the problem and the suitability of a particular scientist or team to work on that problem. Sometimes it is necessary to prepackage problems. We recognize the need. What is suggested, however, is that we give problem identification proper recognition for its importance in the research process. Additionally, it is suggested that when prepackaged problems must be assigned to scientists or teams, arrangements be made to allow the scientist or team to develop a comprehensive understanding of the problem area. All of this is germane to our discussion of statistics because no amount of skill in design, analysis and interpretation can compensate for a poorly chosen research problem.

OBSERVATION

The next step in the research process is to observe the system relative to the problem. The objective is to determine some basis for an intervention strategy for problem resolution. We would like to identify those factors associated with the problem and narrow our choices to evaluation of a few factors with a high probability of success. We have two obvious choices. personal observation and vicarious observation. Either of these will be acceptable if they are based on accurate observations. This points out the need for well-designed observational research. It can be done either as part of the sequence of problem solving or as research supportive of problem solving. How much valuable information have we lost because it was not recorded for posterity? How many times have we repeated what was already done because we did not know about it? We need to put the emphasis on this stage of the research process that it deserves. We need to give scientists time and credit for observational research. Without proper observation of a system it is unlikely that we will stumble onto solutions to real problems.

HYPOTHESIS FORMULATION

Hypothesis formulation is a natural consequence following properly performed problem determination and observation. I mention it for sake of completeness although many feel that it is the first step in the research process. Hypotheses formulated should be clearly stated, simple and testable.

HYPOTHESIS TESTING

Hypothesis testing is an important area and receives the most attention and funding. We use a lot of our skills in statistics in the disciplines of sampling, experimental design, and data analyses. We sometimes feel most vulnerable in this area. In hypothesis testing, we are concerned with two primary issues: collection of unbiased evidence and collection of conclusive evidence. We want to avoid bias in our estimates of parameters of interest such as mean differences and variability and we want our estimates to be sufficiently precise.

Bias

The choice of the sample used in research has a direct bearing on whether or not estimates will be biased. It is a fact that the choice of experimental units used in many research projects is based on economics or convenience. It should be pointed out that the choice of experimental units may bias our estimates of differences if the experimental units interact with the treatments in the experiment. If the experimental units are a non-random sample then we may not have an unbiased estimate of error variance. An example to support this would be the use of Brahman half-sibs in a forage evaluation trial. Differences among the forages may depend on the breed used in the experiment and the among animal component of the error variance would be biased downward because of the correlation among the half-sibs.

The sample we choose should be representative of the population to which inference is to be made. Here is where we have to use some common sense. Economics is a real factor to all of us. If we choose a large inference population, we will need major resources to obtain a representative sample of that population. We actually have two other alternatives; we can participate in a cooperative effort to share resources or we can reduce the scope of our inference. I do not want to digress on cooperative efforts, but clearly some realignment of our current positions on cooperative research could be beneficial. Additionally, the size of the inference population is not particularly proportional to the quality of the research. Our goal is to get unbiased estimates.

Bias must also be avoided in the assignment of treatments to experimental material. We are encouraged to assign treatments at random to experimental units, according to the design of the experiment. We have to use some common sense in doing this, particularly with the low sample sizes that we routinely work with. The goal is to obtain unbiased estimates and to do this we must assign treatments so that differences that we observe between treatment groups are due to the treatment and not to some inherent difference between the groups prior to application of treatment. Common sense would suggest that if you are uncomfortable with your randomization because of potential bias, change it.

Experimental design is simply the arrangement of experimental material to avoid bias and manage the precision of the experiment. Randomized complete block designs, for example, restrict the randomization of treatments so that differences among treatments are unbiased. The quality of an experiment depends on the appropriate choice of an experimental design, not the complexity or popularity of the design. Ideally, a design should be as simple as possible but effective in management of bias and precision. Overly complex experimental designs tend to cause heartburn when data is lost or the distribution of the response requires a nonparametric or categorical analysis. One final comment—good design requires that we know something about the responses of our experimental material prior to application of treatment. If we do a good job in the observational stage of the research process we will have the necessary information.

We also need to avoid bias in the management of our experiment as it is conducted. Potential exists for our management inputs to interact with the treatments in the experiment, or for differential management or for management changes to occur. All of these are potential sources of bias in an experiment. We all want to be good managers but we need to use common sense in our management to insure that we do not introduce bias.

Bias can also easily occur in the collection of data through biases in measurement instruments, time, personnel, recording or transcription or from many other sources. Common sense is an important component of this part of the research process to avoid these sources of bias.

The final source of bias to be concerned with is bias introduced in the statistical analyses of the data. If the data are not normally distributed, significance levels of standard tests of hypotheses may be biased. If data are missing, least squares procedures should be used to minimize bias in estimates of parameters. If a mixed model design is used and data are missing, mixed model procedures should be used to minimize bias in estimates. The potential for bias is greater than in the past because of the advent of canned statistical software and its misuse. Common sense can prevent a number of problems in statistical analyses if properly applied.

Precision

After bias, the other issue that we deal with in research is the precision of the estimates. The actual question being asked is whether or not we could expect the same results were the experiment repeated. The precision of our research depends on a number of factors. Sample size is one of the most important factors in the precision of our research. The variances of the parameters that we are estimating are constant with the exception of the sample size component of that variance. We are often faced with the question of determination of sample size. To answer that question we must have information about parameter sizes that are important to us (e.g., the size of a difference in means that we want to detect), a good estimate of the associated variances, and acceptable levels of error rates in the experiment. In reality, sample size is most often determined by economic criteria and consequently most experiments are under-replicated. Again, we see a rationale for cooperative efforts in research we do. One other interesting aspect of sampling is the relationship between the precision of our research and the inference population in the research. A general rule of thumb is that a larger inference population is associated with larger inherent variability and the sample size required for acceptable precision will be larger.

The obvious question at this point is how do we apply common sense in managing the precision of our experiments through the choice of type and number of experimental units? I believe that the following points are germane to this:

- We can reduce our inference intent to more reasonable populations.
- We can increase acceptable error rates in our experiments.
- We can increase the detection level of parameter size.
- We can pool resources and cooperate.

I do not recall any universal law that states that good research has a worldwide inference base, although useful conclusions will obviously extend beyond our local commuting areas. I am not certain who came up with the idea that the observed significance level had to be less than 0.05 to reject a null hypothesis or that our probability of a Type II error had to be less than 0.05. The inference population, error rates, and detection sizes all must be determined on a case by case basis for each experiment. Common sense tells us that if we are not willing to do one or more of the suggested points then we are going to have to try for increased funding. In our current environment, this seems to be the least likely choice.

Other factors certainly influence the precision of our research. Measurement error can decrease our precision. It is not unreasonable to question whether or not an experimental unit is being measured precisely, particularly in the case of large land areas. The variance of subsamples is a consideration in determination of the total sampling plan. A rule of thumb is that precision in tests of hypotheses is more closely associated with the number of replicates rather than number of subsamples, i.e., do not over-sample your experimental units at the expense of replication.

The experimental design is intended to manage precision of the research. For example, we know that the variance of a difference is the sum of the variances minus twice the covariance. If we induce covariance among our experimental units, we can reduce the variance of treatment differences. We do this in paired experiments, randomized complete block designs, and split plots. Thus, to be effective in management of precision we need sufficient knowledge of our experimental material. This relates to the observational stage of the research process and again suggests the time spent in the initial stages of research is very important.

One final stage of the research process associated with precision is in the statistical analysis. Seeming increases in precision through transformations are actually corrections for bias. The common sense approach to analyses is to perform them according to the design of the experiment. There have been too many randomized complete blocks analyzed as completely randomized designs and split plots analyzed as factorial treatment designs.

SUMMARY AND CONCLUSIONS

I was asked to avoid lecturing on statistical methods when I was invited to speak at this symposium. I did not successfully honor that request, but I hope I sufficiently communicated the fact that we are being too dogmatic in our approach to the use of statistics in the research process and to the research process in general. I am suggesting we are overemphasizing the hypothesis testing stage of research at the expense of other stages which ultimately detracts from the efficacy of that stage by feedback. I am also suggesting that we are faced with information problems in sharing what we learn from all phases of the research process. Lastly, I am suggesting that we do not take advantage of opportunities that are presented through cooperative efforts. The title of this presentation, "Common Sense and Statistics", is intended to prompt us to think about the bases of what we are doing in research. The major theme I tried to communicate is that if we excel at problem determination and observation of our target system and succeed at managing bias and precision in our research, then we can accomplish good research. Statistics is a part of the process and involves the application of common sense. We have some challenges that face us today, in funding, in time and in our roles as scientists. I hope that this discussion has been helpful to us as a basis for overcoming those challenges.

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Simulation Modelling for Hypothesis Testing

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ABSTRACT

The way we precieve a system will determine the conclusions we draw from data collected from that system. To optimize our thinking concerning the analysis of agricultural information, methodologies developed though systems analysis are investigated. Statistical models and structural models have their place in science, but both most be validated. The best validation will combine inductive and deductive reasoning. Our challenge is to apply these reasoning methods with the proper perspective, so that we can attain our final goal—to enhance our ability to understand, predict, and control the behavior of agricultural systems.

INTRODUCTION

As of recently I have been considering the question "How in science do we actually solve problems?" and I have come up with a principle that how you individually view the world, that is your particular philosophical bent to life, predestines your conclusions. So, no matter what you are going to attempt to solve as a problem, because of your philosophical bent you may have already solved that problem and it will be reflected in the conclusions you draw. That is. ignore the data (see Brown. this volume). Thus. through personal experience, you have what you think is an outlier and, using common sense, you throw that data point out. Eventually the "sense" of the scientist prevails and its his philosophical thought that predestines what conclusions should be drawn.

So. how do you view the world you live in? Do you do your work the same this year as last year—year after year after year? Or are you trying new and innovative approaches to solve problems and build knowledge, so you are doing all you can to understand the system you work in. Several papers presented in this symposium have emphasized the complexity of agricultural systems. John Stewart (this volume), for example, challenged us is no uncertain terms, that reductionism was really inadequate for expanding our knowledge into the total workings of the agricultural system. In other words. we must simultaneously examine the interaction of plants, animals, soils, hydrology, insects, management, and economics instead of looking at them as individual entities (Fig. 1). One method for optimizing our thought in the study of these complex systems is the use of simulation modelling and systems analysis.

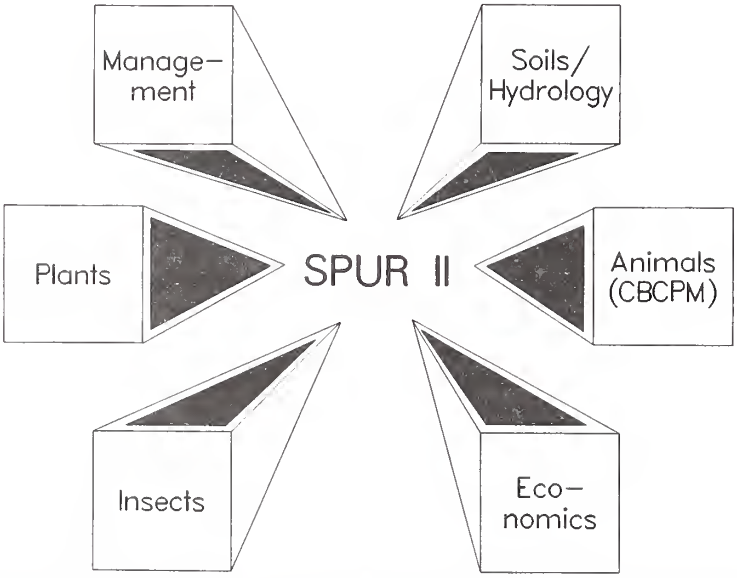

Figure 1. Important components of the agricultural system as represented in the SPUR Phase II model.

SYSTEMS ANALYSIS

As we begin our discussion, some definitions should be made. A model is a simplified representation of a system (or process or theory) intended to enhance our ability to understand. predict, and possibly control the behavior of the system. Modelling, then, is the process of establishing interrelationships between important entities of a system, and models are expressed in terms of *goals, performance criteria, and* *constraints*. I have heard some pretty strange definitions of a system. for example listen to this recently published one: to state or pose large-scale complex problems correctly, to model the relationships in a realistic yet computable manner. and to follow up the system through its life cycle. Or from the same paper, how about this one: a unique system is a set of solutions to the defined problem via a model incorporating the disciplinary knowledge of the interdisciplinary group. Perhaps a more digestible definition states a system is a set or assemblage of entities (elements or components) interrelated to each other and to the whole so as to achieve a common goal. The emphasis is on the organization of components that act together, and not on the individual elements.

Scientific Method

A major component of any scientific investigation is the scientific method. In way of review, the scientific method consists of several steps:

1. Accurate recording of observations and definition of the problem.
2. Formulating hypotheses with the aid of imagination and creative ability.
3. Testing the hypothesis by experimentation, and if necessary, reforming the hypothesis.
4. Confirming that the hypothesis is equally valid for all reasonable people.
5. Defining methods capable of disproving the hypothesis by others.

Approaches to Modelling

Much of the work within the field of systems analysis involves constructing the appropriate model to describe the system of interest. Two primary methodologies for examining and analyzing systems involve statistical modelling and structural modelling.

Statistical Models

The objective of statistical modelling is to develop a relationship between observed output and known input of a system by postulating a general mathematical relationship and then estimating the relationship by adjusting the parameters to best fit the empirical data. This approach has particular merit where little knowledge of possible relationships exists. The problem of using statistical models for analyzing systems is that the available knowledge of system structure is not used. Concomitantly, the parameters generally have no meaningful counterpart in the real world system. However, as we gain more knowledge and information concerning the Great Plains—how these systems work and hang together—we need to ask more questions need to emphasize why and how a particular system works!

Structural Models

For structural modelling an effort is made to improve, over statistical models, model validity (structural, behavioral, empirical, and application validity) by describing system structure and system elements as well as possible. In developing these models, the elements of the model correspond to real elements of the real system and functions that represent the elements of the system are modelled after those of the real system. Also, the structural connections between the elements correspond to identifiable relationships in the real system and parameter values, initial conditions, inputs, etc. correspond to identifiable quantities in the real system. Thus, if the structure is modelled faithfully, the model may contain the same dormant structural components as the real system (emergent properties), which may be activated under certain conditions and may lead to different behavior modes not observed in the past.

Structural modelling purports several advantages. These include, but are not limited to:

- Behavior predictions are more reliable.
- Parameters have physical meaning and should, therefore, be measurable.
- With their emphasis on structure and resulting behavior, structural models provide a much better understanding of the system being studied.

This brings up an interesting question—if you run a model, can you believe the results? Somehow we need to determine the amount of truth contained within a model.

MODEL VALIDATION

Regardless of the modelling approached pursued. the investigator must be concerned with how well the developed model corresponds to the real system. In the strictist sense, model validation means to demonstrate that the model is true or an exact replica of reality. No model can be an exact replica of a real world system, thus validation concerns itself with the quantification of how close to the real system the model is. So, in the strictest sense of the word. models can not be validated. Modelling is not a precise science. Therefore, different criteria should be used to test models as opposed to other scientific theories. Since, validation is substantiating that the model is sufficiently accurate within its domain of applicability for the intended application, emphasis is on establishing confidence in the model rather than testing for its absolute validity. Model sponsors, model builders, and model users must be prepared to accept compromise solutions.

Methods of Reasoning

Before looking at methods of model validation, let's consider the two primary types of reasoning involved in science and then see how those reasoning approaches affect the validation process. Scientists usually follow one of these reasoning methods over the anther, and again, it depends on our personal philosophical bent.

Inductive Reasoning

Inductive reasoning is the method of drawing conclusions by observing, collecting evidence, and detecting patterns. It is based on extrapolation of trend derived from known data. Thus, the inductivist theory assumes that the ultimate reality can be accessed by amassing data from observations and then formulating an hypothesis to fit all the data. In general the inductivist would argue from the particular to the general.

Deductive Reasoning

Deductive reasoning is the method of drawing conclusions by logically combining new ideas with facts we accept as true; that is reasoning from known principles to deduce the unknown. Deductivist theory emphasizes the importance of the relative rather than the absolute nature of truth. It introduces the notion of *falsifiability* as opposed to *provability* of a theory. Even though a theory can never be proved, its robustness can be judged in terms of its ability to withstand detailed persistent, and severe tests aimed at disproving them. Thus, the deductivist arguing from the general to the particular.

Approaches to Validation

I would like to consider three types of model validation.

Positivist Approach

The positivist approach accepts the validity of a model if it is capable of accurate predictions, regardless of the internal structure and underlying logic of the model. This approach would be used in the validation of statistical models and should be considered unacceptable when attempting to analyze the structure of ecological systems.

Empiricist Approach

The empiricist would refuse to accept any axioms, theories, or other assumptions including obvious ones without positive evidence, and validation involves the collection of empirical data (evidence) to support the postulates or assumptions. This is the general approach taken for data analysts. When analyzing systems this approach adds credence to models and should definitely be the goal during any model development. However, for most large-scale simulation model, data is not always available. This lack of data should not, by itself, invalidate a model.

Rationalist Approach

The rationalist would accept that the model is basically a set of logical deductions from a series of premises whose truth is obvious and unquestionable, and here validation reduces to the question of tracing the fundamental assumptions on which the model is based. If the premises are accepted then the model is accepted. The rationalist doesn't ignore data when they are available, but conversely, is not thwarted when data are not available.

CLOSING REMARKS

Many times we as modellers are envisioned as magicians who have a tool box full of methodologies whose complexity rivals that of the Star Wars Defense System. And those of you who are not modellers probably wonder if modellers really do think. My challenge to modellers is to quit building models for modelling sake. Rather, let's begin to invest our time in synthesizing information so that we gain a deeper understanding of how a particular system really functions. And to modellers and nonmodellers alike, don't be so quick to base the validity of a model only on the basis of field collected data. Perhaps, if we apply these reasoning methods with the proper perspective. we can gain our final goal—to enhance our ability to understand, predict, and possibly control the behavior of agricultural systems.

Soil Survey Databases for the Great Plains

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INTRODUCTION

The Soil Conservation Service (SCS), through the National Cooperative Soil Survey (NCSS), collects and maintains soils databases at various levels of abstraction and application. There are two major categories of computerized soils databases: attribute databases and geographic. Attribute databases store textual and numeric data values which describe soil properties. These are stored in two-dimensional tables or data files. Geographic databases contain soils information which can be displayed as a map. These databases represent soil map unit delineations or polygons. The polygons are identified on the map with a unique symbol for each map unit. Site specific data, such as pedon descriptions, are also identified in geographic space using a geographic coordinate system such as latitude and longitude. The integration of geographic and attribute data using a geographic information system (GIS) creates a very effective tool for supporting land-use decisions.

This paper[3] presents a discussion of the major attribute and geographic soil databases maintained by the SCS, discusses the implementation of these databases in a physical computer environment, and presents a brief discussion of plans for the integration and management of these databases in the future.

SOIL ATTRIBUTE DATABASES

Tabular databases that contain data describing soil attributes can be separated into three different types:

1. those containing attribute data expressed as a range, which record the variation in soil properties over geographic space,
2. those that contain data for a specific site, with data commonly expressed as single values, and
3. those that record information about soil performance (yield, for example).

Data Expressed as a Range

Official Soil Series Description (OSED)

OSED consists of the narrative description of each soil series in the United States and the trust territories. It establishes the standard definition of the series and, along with the Soil Classification file, is the tool used in quality control and quality assurance to determine if soils of a specific survey are classified correctly (Soil Survey Staff 1972).

The file is maintained by the Statistical Laboratory. Iowa State University (SL-ISU) and can be accessible via the Soil Classification File. Because it is essentially a text file structure, it is not very useful in searches for specific properties of soils or for building models that describe soil processes. Plans are to convert these text descriptive data to tabular format to be more compatible with computerized access and validation.

Soil Classification (SC) File

The SC file includes information on the taxonomic classification of over 17,000 soil series of the U.S. It also contains information on when the soil was established, the state that maintains the series information, and states that use the series.

The file is maintained by the SL-ISU in a hierarchical (SPIRES) database management system (DBMS). It is accessible interactively or via batch mode. Searches can be made at any categorical level in soil taxonomy using any data element and linked to the OSED to generate printed descriptions of the selected series.

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[3] Adapted from the paper entitled "Soil survey databases and their uses" by M.J. Mausbach, D.L. Anderson, and R.W. Arnold.

Soil Interpretations Record (SIR)

The SIR (Soils-5) database contains estimated properties of the soils of each series including interpretations for engineering, water management, recreations, agronomic, woodland, range, and uses of the soil. The database contains data for more than 30.000 soil series or phases of soil series. It provides an estimated range of over 25 properties for the major layers of a soil series. The properties include particle size distribution, bulk density, organic matter, available water capacity. soil reaction, and salinity. Flooding, water table, bedrock, and subsidence characteristics are also given.

Interpolations include sanitary facilities. building development, recreational development, important crops, woodland, wildlife habitat, and rangeland (Soil Survey Staff 1983). The interpretations are presented as limitations (slight, moderate, and severe) with limiting properties listed.

The SIR is available via batch access at the SL-ISU and also available interactively at the National Computer Center, Fort Collins, Colorado (NCC-FC) in the System 2000 hierarchical DBMS. The SIR is currently stored as a conventional flat file. The SL-ISU is in the process of converting the SIR to a relational database management system (RDBMS). The data will then be available for both interactive and batch access and via nine-track magnetic tape for computers of other users.

The SIR is the most widely used soil survey database. The ranges in properties stored in the SIR database are useful in developing models that reflect soil behavior. Land-use planners use interpretative predictions in developing local and regional plans and many localities base ordinances on both the interpretative and properties data in the record. Yield predictions are useful in developing relative productivity of soils in an area.

Map Unit Use File (MUUF)

The MUUF file contains information on map units in over 2,600 soil survey areas of the U.S. (Soil Survey Staff 1983). It includes information on name and symbol of each soil map unit, counties where mapped, acreage of each unit by survey area, percentage composition of multi-taxa units, and SIR numbers that link map unit components to the SIR data. Data are stored in relational tables in the ORACLE relational database management system (RDBMS) at the SL-ISU.

Map Unit Interpretations Record (MUIR)

The MUIR contains all the data elements stored in the MUUF and the SIR. However. the data are presented as single phase estimates of properties and interpretations for components of map units of a soil survey area. The data in the MUIR can be tailored to represent local ranges in data. It is a new database that requires the informed judgments of soil scientists in addition to information in the MUUF and SIR databases. Many states have not had the resources to tailor the entire state database yet.

The MUIR data structure is maintained at three levels. It is available interactively for all correlated soil map units in the U.S. in a database called the *National Soil Survey Area Database* (NSSAD). NSSAD is on the USDA, National Computer Center System 2000 Hierarchical DBMS at Fort Collins, Colorado. The data in the NSSAD database represent single phase records for soil map units but has not been tailored by soil scientists to represent local variations in data. The MUIR data for all map units in a state is maintained as relational tables in a RDBMS in the *State Soil Survey Database* (SSSD). SSSD is available in SCS state offices and is managed on a micro-computer in a UNIX environment. SSSD contains the official or master MUIR. The SSSD database is being edited to reflect local variations in data as staff time within the state permits. The MUIR in SSSD can be segmented and downloaded for a single or group of soil survey areas (a survey area boundary usually coincides with a counties boundary). This creates the records for the soils databases in the *Computer Assisted Management and Planning System* (CAMPS). CAMPS is used by SCS soil conservationists for planning conservation systems. At the present time both a UNIX and MS-DOS version of the database exit.

The relational structure of SSSD and the soils database in CAMPS allow access via a database query language which allows flexible, easy manipulation of data. In addition to providing specific data for components of map unit to run models, the MUIR contains yield data for map units of a soil survey area. At the field office level, the MUIR serves as the Field Office Technical Guide for soil information. At the national level, many users query the national database to check internal consistency of the data and to generate summaries of soils that have specific properties.

Site-Specific Databases

Site-specific databases contain data collected via the pedon sampling unit in a soil survey, a point on the landscape. This point data represents sites that are sampled for laboratory characterization, detailed soil descriptions, or for collection of performance data. Points are normally sampled to represent a specific soil series, or map unit component. Site-specific databases in the NCSS include the *National Soil Characterization Database* (NSCDB), pedon description, and soil engineering databases. The NSCDB is in the design stage but will contain the National Soil Survey Laboratory database when operational.

National Soil Characterization Database (NSCDB)

The NSCDB will house the soil characterization data collected in support of soil survey operations. It will contain the SCS soil characterization data of the National Soil Survey Laboratory (NSSL) as well as data from cooperating land grant universities. The database is in the design stage. The NSCDB will house both analytical and morphological data for pedons including particle size, bulk density, cation-exchange capacity, base saturation, soluble salts, organic matter, mineralogy, and other chemical analyses required to classify and interpret soils (USDA 1981). Presently the NSSL has a database of about 25,000 pedons (records) of analytical data. Morphological data for about one-third of the pedons have been coded. The data are available from NSSL, at no cost to NCSS cooperators, either interactively or on magnetic media, and are available to others for the cost of duplication.

The analytical and morphological pedon data are useful for developing relationships among soils and data elements and for developing models of physical processes with respect to soil performance under various uses. The data are collected to characterize soil series, test genetic relationships, or solve interpretive problems. They are not representative of the entire range of properties of a soil series. The pedon data are used in the development of ranges in properties in the OSED, SIR, and MUIR databases.

Pedon Description Database (PDP)

The pedon description database consists of the morphological descriptions collected as support data in project soil surveys. The data are coded site and layer data for pedons that are selected to represent soil series concepts or map unit components (mostly phases of soil series) (Mausbach and Stubbendieck 1987). The data are stored in relational tables suitable for use in relational databases for the microcomputer.

The data are summarized to generate property tables and summary descriptions for the soil survey report of a survey area. The data are also used to support the national standard or definition of a soil series as given in OSED or SIR databases.

Soil engineering Test Database

This database, when operational, will contain information on the engineering properties of soils such as particle size distribution, liquid limit, plastic index, and engineering classification of the soil material. The data are from SCS Soil Mechanics Laboratories and state highway laboratories. The SCS has data for thousands of pedons in paper copy.

Soil Performance Data

SCS soil scientists, conservationists, agronomists, foresters, and range conservationists collect soil performance data for soil map unit components. The data are summarized and shown in soil survey reports and are used in local Conservation District Field Office Technical Guides. The performance data are also summarized by phases on the SIR for predicting suitability of soils for various crops and plant species. The performance databases include crop yield (CRPYL), soil-range, and soil woodland and windbreak databases.

Crop Yield Database (CRPYL)

The CRPYL contains yield data of common crops for components of map units or soil phases (Soil Survey Staff 1988). The database contains information on the site, soil, management practices, insect and pest damages, climate, climate-related damages, cultivar, and crop yield. The database is designed for collection of multiple years of data at specific sites, thus representing many climatic conditions and crop sequences. The database is presently at the National Computer Center, Kansas City (NCC-KC) and is a formatted flat file. The SCS plans to load the data to the ORACLE RDBMS.

Soil-Range Database

This database contains range site information for more than 8000 sites. Data elements include grazing history, kind of animals, site condition, cryptogram cover, plant names, plant clipping data site characteristics, abbreviated soil descriptions, and soil classification (Ecological Series Staff 1976a). The database is located at the NCC-FC. It provides background performance data for range sites and soil phases and is useful for tracking range production under different grazing histories and how range composition varies with use.

Soil-woodland and Windbreak Database

This database contains data for more than 22,000 sites by phases of soil series. Data include tree species, age height, diameter, condition, suppression, site characteristics, abbreviated soil description, and soil classification (Ecological Series Staff 1976b). The database is located at the NCC-FC and is useful for determining productivity of soils and for determining species that are adapted for specific soil series.

GEOGRAPHIC DATA

The NCSS has three soil geographic databases that represent different scales of soil mapping. They are the National Soil Geographic Database (NATSGO), the State Soil Geographic Database (STATSGO), and the Soil Survey Geographic Database (SSURGO) (Reybold and TeSelle 1989). Digital geographic data are available for the cost of duplication from the SCS National Cartographic Center, South National Technical Center, P.O. Box 6567, Fort Worth, Texas 76115.

National Soil Geographic Database (NATSGO)

NATSGO is the digitized Major Land Resource Area (MLRA) map for the U.S. on a scale of 1:7,500,000 (USDA 1981). The database is useful for state, regional, and national planning. The soil components of the MLRAs were determined by a statistical field sampling method and recorded during the 1982 National Resource Inventory (NRI) (SCS 1979). Components are mostly phases of soil series and are linked to the SIR database to provide attribute data for generating interpretative maps.

State Soil Geographic Database (STATSGO)

STATSGO consists of general soil maps on a 1:250,000 USGS quadrant format for each state. They are created by generalizing from detailed soil surveys and from unpublished soil surveys (Reybold and TeSelle 1989). The components of the general soil map units are determined by generalizing from detailed maps and linked to the SIR to generate attribute data. The database is useful for regional and statewide resource planning purposes (Bliss and Reybold 1989).

Digital and attribute are in vector format suitable for use in the ARCINFO GIS system. They are available from the SCS National Cartographic Center in Fort Worth, Texas. STATSGO data are presently available for about 20 states.

Soil Survey Geographic Database (SSURGO)

SSURGO is the digital data for detailed soil surveys. To meet national specifications, the survey area maps must be on orthophotography in a 1:24,000 quadrangle or 1:12,000 quarter quadrangle format (Cartographic Staff 1980, Reybold and TeSelle 1989). The MUIR database for the soil survey area is used for attribute data. To data there are about 150 soil survey areas digitized nationwide that meet SCS specifications.

FUTURE DEVELOPMENT PLANS FOR SOIL SURVEY DATABASES

The data and information in our soils databases are a critical national resource for quality natural resource planning and management. This resource is shared by a large clientele of scientists, technicians, and laymen who's needs are constantly evolving. The demands for soils data are becoming more frequent, require data to be organized into larger bodies of information, require more integration with other natural resource data, and require more precise data than in the past. The increased emphasis on water quality, the use of models to simulate natural processes, and the trend to use soil characteristics for defining national policy objectives are helping to drive this demand.

These demands are creating new requirements for soils information. To meet future needs, soils data must be organized, documented, and administered using current industry data management technology and standards. The Soil Survey Division is in the process of an intensive analysis of the major soil survey databases. The objective of this analysis is to develop, implement, and maintain an integrated soil information delivery system which will meet the demands of the future and provide detailed documentation of systems requirements.

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Research Networks for the Great Plains

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INTRODUCTION

The organizers of this Symposium asked me to make some suggestions and comments regarding research networks for the Great Plains. Before doing this, however, I believe it is essential that we spend a few moments discussing what we mean by a research network. I suspect that everyone in attendance can define a research network, but I also suspect that we could spend many hours trying to agree on a definition acceptable to the entire group.

What are Research Networks?

A "critical mass" of scientists is needed to develop new knowledge through basic and applied research. In many cases, a single organization does not have enough scientists working in a given area or on a particular problem to achieve this critical mass. Therefore, networks are developed to build a critical mass through the collective joining of scientists.

Types of Networks

1. Information Exchange Networks—Organize and facilitate exchange of ideas, methodologies, and report research results. A professional society is an excellent example.
2. Scientific Consultation Networks—Involve participant-by-participant focus on common priority research areas, hold regular meetings and provide other means to exchange information as in Type 1 above. Research is initiated and implemented independently by the participants. Regional projects sponsored by the Cooperative State Research Stations (CSRS) are an example.
3. Collaborative Research Networks—Involve joint participant planning, implementing, and monitoring of research on a problem of mutual concern. These networks also include information exchange and technical collaboration like the networks above. Some CSRS regional projects are of this type.

Most proposed networks are probably perceived to be Type 3, but end up performing as Type 1, or Type 2 at best. Successful Type 3 networks require some actions which are often difficult to achieve. Consequently, networks are not easy to implement.

Characteristics of Collaborative Research Networks

There are several characteristics which appear to be essential for effective collaborative research networks (Type 3) and some of them are as follows:

1. The network should be developed around an important objective and address subjects perceived to be important to the area served.
2. A clear and well-defined theme or strategy is essential and it should be within the resource capabilities of the participants.
3. An existing or identified source of ideas or improved technologies to drive progress. Successful research networks must be envisioned to be more than periodic meetings of scientists.
4. A coordinating organization to facilitate activities and provide technical guidance. A coordinating institution is essential to ensure a smoothly functioning and productive network.
5. A steering committee composed of participating scientists to provide technical leadership and policy direction to the network.
6. Regular meetings of participating scientists to identify goals and specific topics to be studied. decide the role of each participant, and review results of previous research.
7. An information exchange system consisting of a regular newsletter or other type of media to disseminate information of mutual interest.
8. Free exchange of ideas, methodologies, and results.
9. Special funding.

Classifying Networks

It would be difficult, and perhaps meaningless, to classify networks into one of those described because there is a continuum between the two extremes. However, there is a critical need to consider this continuum before a network is formed. Based on my perspective, scientists want to be associated with Type 3 networks, but for various reasons, most networks are a long way up the continuum toward Type 1. One of the primary reasons for this is that network organizers are reluctant to exclude participants who show an interest, even though their research may be on the fringe of the network objective and strategy. Consequently, the strategy loses focus and the objective is not met to the degree perceived at the time the network was formed. This is not to say the network was ineffective, only that the network which developed was different from the one originally perceived.

Other reasons that Type 3 networks are difficult to achieve is the lack of financial and time resources. Most scientists already have their resources allocated at the time a network is being formed so they do not have the flexibility to immediately make a sizable shift in their program. Special funding for networks can be very effective because the judicial use of limited funds can often focus the use of other resources on a particular subject.

HISTORICAL NETWORKS IN THE GREAT PLAINS

The Great Plains region offers a truly unique setting for a research network because of the systematically increasing temperature from north to south and increasing rainfall from west to east. Therefore, a matrix of locations allows for many combinations of temperature and precipitation variables. Using dryland farming as an example, it is interesting to review how research networks have developed and changed with time. The first research network was probably the exchange of information between the State Experiment Stations formed following the Hatch Experiment Station Act passed by the U.S. Congress in 1887. The Act provided federal grants for agricultural experimentation and a cooperative bond between the USDA and the nation's Land Grant Colleges. Headquarter locations of the State Experiment Stations, in relation to the Great Plains, are shown in Figure 1. Without exception, the station headquarters are on the fringe or completely outside the region that most scientists designate the Great Plains. It is no doubt safe to assume that this network was way up the continuum scale toward a Type 1.

During the period between about 1906-1914, the USDA Division of Dryland Agriculture established Field Stations at a number of locations in the Great Plains. These locations are shown in Figure 2. In addition to the locations shown in Figure 2, there were USDA and State Agricultural Experiment Stations conducting agricultural research not under the auspices of the Division of Dryland Agriculture. The Field Stations operated by the Division of Dryland Agriculture probably made up a Type 3 network because the research plans were centrally formulated and directed. Major efforts were focused on evaluating crops and crop varieties for the local area, and to design crop rotations and management practices to maximize crop production and erosion control. The data from these locations were of immediate value to

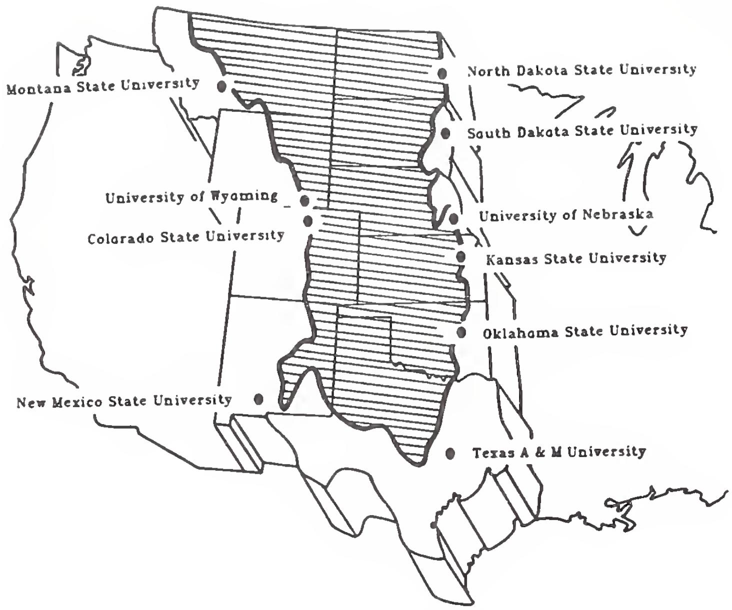

Figure 1. Headquarter locations of the Land-Grant Universities.

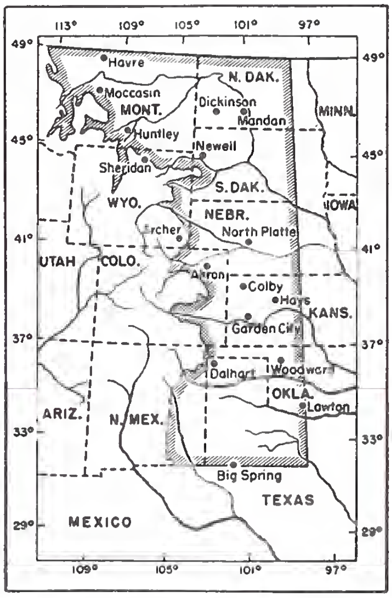

Figure 2. Locations established by diversion of dryland agriculture in the early 1900s.

early farmers, but they also provided a valuable base of information for future studies. For example, this early network established the base data that were used in the classic USDA Bulletin "Nitrogen and Carbon Changes in Great Plains Soils as Influenced by Cropping and Soil Treatments" by Haas et al.(1957) and for much of the work presently underway by C. V. Cole and colleagues.

The Division of Dryland Agriculture was terminated in 1938 and although networks continued, the networks have for the most part continuously moved toward the Type 1 end of the network continuum. Of the locations shown in Figure 2, only four (Mandan, ND; Akron, CO; Woodward, OK; and Big Spring, TX) of the original dryland agriculture stations are still operated by the USDA. However, I believe that only three (Newell, SD; Dalhart, TX; and Lawton, OK) have been completely abandoned as research locations. The others have been transferred to the State Agricultural Experiment Stations.

The USDA Agricultural Research Service was formed in 1953 and some dryland farming activities of the Soil Conservation Service were combined with those from the Bureau of Plant Industry, Soils and Agricultural Engineering. Since 1953, research networks within the Agricultural Research Service have changed a number of times due to changes in organizational structure and allocation of resources. The unmistakably clear trend over the past few decades has been for less structured research networks in so far as resources being allocated and managed from a single focal point.

The Great Plains Agricultural Council, made up primarily of the ten Land Grant Universities and USDA Agencies of the Great Plains, sponsored for many years committees on particular subject matter areas. These committees certainly served as networks, and varied in degree of focus. As a whole, they tended to serve more as information networks rather than as collaborative research networks. A recent restructuring of the Great Plains Agricultural Council has resulted in disbanding these networks.

FUTURE RESEARCH NETWORKS IN THE GREAT PLAINS

The very short and incomplete discussion presented above indicates that future networks in the Great Plains will depend on initiatives generated by scientists. However, as pointed out earlier, it is essential that a smooth running and effective collaborative research network have a coordinating institution. This continues to present some difficulty in the Great Plains because the major coordinating institutions do not include all of the Great Plains. There are adequate mechanisms available to form collaborative research networks, but I believe it will take strong leadership by interested scientists to work with the various administrators to "make a network happen."

SPECIFIC RECOMMENDATIONS

Cropping systems are important to every agricultural area, but they are of particular importance to the Great Plains because they must provide protection of the resource base as well as profitability to producers. Legislation is mandating an emphasis on sustainability.

I am recommending that a collaborative research network on cropping systems in the Great Plains be favorably considered. A workshop on cropping systems would be beneficial and could serve as a forum for discussing the needs and opportunities for a cropping systems network. For example, research at Akron, CO is showing wheat—corn fallow an efficient cropping system in the Central Great Plains for obtaining two crops in three years, while Bushland, TX uses wheat—sorghum fallow. Bushland is about 700 km south of Akron. Do we know enough to make sound recommendations where corn and sorghum should be switched in the system? Millet is becoming an important alternative crop in the Central Great Plains, while receiving practically no attention in the Southern Great Plains.

SUMMARY

The Great Plains region, because of distinct temperature and rainfall gradients, offers an excellent natural setting for collaborative research networks. However, the trend of the last few decades has been a shift toward informational networks, rather than research networks. As networks are discussed and considered, it is extremely important to determine clearly the objective and strategy. While informational networks are relatively easy to form, collaborative research networks are difficult to form and manage, but can be extremely fruitful. We should settle for nothing less.

A Geographically Referenced Information Delivery System

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Anderson, G.L. and J.D. Hanson. 1991. A geographically referenced information delivery system. Pages 99-108 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

ABSTRACT

The Great Plains System Research Unit, Agricultural Research Service, Fort Collins, Colorado is developing a spatial modelling tool called GRIDS (Geographically Referenced Information Delivery System), which is capable of accepting and outputting geo-referenced data within a spatial framework. GRIDS will have the capability of integrating SPUR modelling output within a geographic information system called GRASS (Geographical Resource Analysis Support System) and an image processing package called ERDAS (Earth Resourses Data Analysis System). Combining spatial technology with system modelling will allow the simulation of system processes within a space-time framework.

INTRODUCTION

Integrated knowledge-bases and effective systems for resource assessment are necessary tools for coping with and forecasting the effect of environmental change on natural resources. The problem involves identifying and monitoring change at various levels and subsequently determining what impact subsequent change will have on ecological structure. The assessment of system processes at multiple levels hinges on the theory that smaller scale processes are indicative of processes occurring on successively larger scales. If this concept is generally acceptable, the consolidation and evaluation of information at selected levels and the development of relationships to aggregate information to the next higher level will be possible. The development of relationships between hierarchical levels will require the linking of system-process within a space-time framework. Two technologies necessary to accomplish this task include spatial-information systems and ecosystem-simulation models (Hanson 1989).

Spatial-information systems are designed to register, portray, and analyze information within a spatial context (Robertson et al. 1988). Two of the more commonly available spatial technologies are geographic information systems (GIS) and remote sensing. GIS technology is a relatively new set of tools originating within the computer-aided cartographic field. The tools allow the entry, placement, and labeling of objects within a spatial-coordinate system (electronic mapping). Various maps, each dealing with separate themes can be manipulated, combined, and analyzed while retaining spatial integrity (Burrough 1986). Geographic information systems also provide an excellent environment for effective use of remotely collected information, such as digitized aerial photography and satellite imagery. The combination of remotely collected data with other geo-referenced data can improve image interpretation and classification. Ecological simulation models attempt to encompass existing ecological theory within a mathematical framework (Cole et al. 1987, Hanson et al. 1988). System models are ideal tools for suggesting trends in specific ecosystem processes, based on available baseline information.

AVAILABLE TECHNOLOGY

The assessment and monitoring of grassland processes over time is very difficult to achieve because of the broad expanse of rangelands, covering approximately 770 million acres in the United States (Society for Range Management 1989), and the high degree of diversity found within and between various range sites. The challenge in this endeavor is to identify meaningful indicators of grassland system performance and to couple the results with efficient spatial-assessment techniques. Various types of remote-sensing devices are available to collect data on a wide variety of subjects.

The most common remote sensing acquisitions used in ecological studies include emission intensity measurements (hand-held spectral radiometer), aerial imagery, high resolution satellite imagery (such as that recorded by the Landsat and SPOT satellite sensors), and low resolution satellite imagery such as the Advanced Very High Resolution Radiometer (AVHRR) sensors found on various weather satellites.

Hand-Held Radiometer

The hand-held radiometer is a non-imaging device that records specific narrow-band electromagnetic energy. A typical hand-held radiometer consists of one probe filtered to sample a portion of the red spectrum (0.6-0.7μm) and the other a portion of the near-infrared spectrum (0.7-0.8μm), representing bands 1 and 2, respectively. This combination of bands can be used to develop a normalized difference vegetation index (NDVI). The NDVI, of the form

$$\text{NDVI} = (\text{band } 2 - \text{band } 1) / (\text{band } 2 + \text{band } 1),$$

normalizes the two bands to indicate the relative amount of green biomass (Deering et al. 1980). Another important aspect of using the red and near-infrared filters is that they record electromagnetic radiation within the spectral regions that are recorded by scanning devices such as the Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM), bands 5,6 and 3,4 respectively, and the National Oceanic and Atmospheric Administration's (NOAA) AVHRR scanners (bands 1 and 2).

The hand-held radiometer was initially designed to provide ground-truth data for studies using thematic-mapper data (Tucker et al. 1980). Radiometers have also been shown to be effective tools for the non-destructive sampling of rangeland biomass. In a study conducted on the Pawnee National Grasslands in Colorado, Pearson et al. (1976) found the ratio between the red and near-infrared bands to be highly correlated ($r^2=0.96$) with dried biomass obtained from clipped plots.

Aerial Imagery

Aerial imagery has been used in classifying, mapping, and monitoring rangelands. Films and devices used at this level include black and white panchromatic photographs, color and color-infrared photographs, single and multiple video recording devices (with or without narrow band filters), and multi-spectral scanners. Aerial imagery has been very effective in delineating, identifying, and quantifying various ecological units (Everitt et al. 1987a, Neck 1987). Aerial video imagery has also been used to identify relationships between spectral reflectance and specific biologically limiting elements such as soil nitrogen and salinity (Thomas et al. 1987, Everitt et al. 1987b).

The development of airborne-video imaging devices has added another dimension to aerial imagery acquisition. Multi-video devices consisting of two or more video cameras, each with a different narrow band filter, have been developed. These devices can be used to emulate the function of more expensive multi-spectral scanning devices within the visible and near-infrared spectrum. Kamlesh et al. (1987) demonstrated the use of spectral transformations, derived from a multi-video device, for distinguishing different range-sites.

Low and High Resolution Satellite Sensors

High resolution satellite sensors, such as the MSS and TM scanners found on the Landsat satellite series, have been used in assessing various vegetation parameters. Deering et al. (1980) found the NDVI of Landsat MSS bands 5 (red) and 6 (near infrared) could provide estimates of the quantity of green forage biomass. Wiegand and Richardson (1984), related vegetation indices derived from Landsat MSS imagery with measured leaf area indices and intercepted photosynthetically active radiation. Other uses for high resolution imagery include cover assessment (Graetz et al. 1982), drought detection (Wiegand et al. 1983), soil moisture budget (Price 1980), and vegetation mapping and monitoring (Haas 1985).

Coarse resolution sensors such as AVHRR, have been effectely used for measuring certain ecological parameters. D'Iorio et al. (1989) found a correlation between AVHRR-NDVI and potential water availability for the prairie provinces in Canada. Coarse resolution imagery also proved useful for mapping vegetation and monitoring change over large areas (Tucker et al. 1985. Gallo et al. 1987). Frequent sampling of large areas is perhaps the most attractive feature of AVHRR imagery (Roller et al. 1986).

SPATIAL TECHNOLOGY AND MODELLING

The combination of remotely-sensed data, GIS layer information, and mathematical models will expand the utility of of all three technologies. Graetz et al. (1983) combined Landsat imagery with a simple vegetation—Landsat response model, within a land image-based resource information system (LIBRIS). The remote imagery provided a means for developing a cover classification, however, information predicting erosion susceptibility was develped by including additional ancillary data. D'Iorio et al. (1989) used precipitation data and digital land-cover and soils maps to assist in determining water availability in the prairie provinces of Canada. Eidenshink et al. (1988) demonstrated the use of the NDVI, derived from the AVHRR scanner, in conjunction with the U.S. Forest Service fire fuel model by identifying and monitoring high fire danger areas. Other applications of remote imagery and mathematical modelling include crop yield estimation (Maas 1988, Gallo et al. 1985) and water resource management (Rango 1985).

The NDVI seems well correlated with a number of ecological parameters (e.g. leaf area, phytomass, nitrogen content) and affected by such things as water availability (Tucker and Sellers 1986). Because the NDVI is related to a variety of variables that are closely associated with plant growth. the index may also have wide applicability in various plant models. An added benefit of NDVI is its transportability. Gallo and Daughtry (1987) found that, under similar viewing conditions, the AVHRR-NDVI could complement other viewing systems such as Landsat and SPOT. In addition to transportability between systems, the NDVI has been shown to be the best transformation to port between AVHRR morning and afternoon image acquisitions (Gallo and Eidenshink 1988).

Simulating Ecological Systems

A thorough understanding of ecological systems includes the competition of multiple plant species and their intrinsic interactions, the heterogeneity of range sites, and the analysis of many other simultaneous processes that control plant-community dynamics (Hanson et al. 1985). Mathematical modelling seems a logical method for identification, interpretation, and management of the biotic and abiotic influences governing rangeland systems and to support on-going empirical research. Simulation models help to integrate our knowledge of hydrologic, physical, and biological processes into a common theory that can be evaluated statistically (Hanson 1989). Simulation models can also be used to examine the consequence of different plant species competing for limiting natural resources, such as light, water, nitrogen, and carbon.

SPUR (Simulation of Production and Utilization of Rangelands) is a general grassland simulation model composed of five basic components: hydrology. domestic and wildlife animals, economics, and plant growth (Wight and Skiles 1987). The goals of the SPUR modelling effort were to 1) evaluate rangeland systems and provide a basis for management decisions, 2) optimize rangeland management systems for desired multiple use products, 3) plan and evaluate land improvement practices, 4) provide a computational framework for investigating the impacts of environmental modifications on alternative management strategies, and 5) forecast the effects of climatic changes on range ecosystems.

The model is driven by daily inputs of precipitation, maximum and minimum temperatures, solar radiation, and wind run. These variables are derived either from existing weather records or from use of a stochastic weather generator. The hydrology component calculates upland surface runoff volumes, peakflow, snowmelt, upland sediment yield, and channel streamflow and sediment yield. Soil-water tensions, used to control various aspects of plant growth, are generated using a soil-water balance equation. Surface runoff is estimated by the Soil Conservation Service curve number procedure and soil loss is computed by the modified universal soil loss equation. The snowmelt routine employs an empirical relationship between air temperature and energy flux of the snowpack.

In the plant component of SPUR, carbon and nitrogen are cycled through several compartments including standing green, standing dead, live roots, dead roots, seeds, litter, and soil organic matter. Soil inorganic nitrogen is also simulated. The model simulates competition between plant species and the impact of grazing on vegetation. Required initial conditions include the initial biomass content for each compartment and parameters that characterize the species to be simulated (Hanson et al. 1988).

Geographically Referenced Information Delivery System

GRIDS attempts to integrate a number of highly sophisticated technologies, such as SPUR (simulation modelling), GRASS (spatial analysis), and ERDAS (data analysis system), into a process-oriented, spatial-assessment package (Fig. 1). Concomitant with the development of GRIDS will be the development of a more sophisticated decision support model ARMS (Agricultural Research Management System) developed from the SPUR model (see Baker and Hanson, this volume). GRIDS development is proposed to progress in two phases.

Phase I will involve the development of a rudimentary interface which will examine the potential inputs and reliability of spatially driven systems models. The study area for Phase I is the Central Plains Experimental Range (CPER), located 12 km north of Nunn, Colorado. Data, such as spatially registered soils, hydrology, and climatic information, required by SPUR will be collected over a growing season. Model results will then be spatially registered within the study area and compared with sample information and remotely sensed data. The primary goal for Phase I, will be to develop relationships between ground-condition estimates, simulation-model results, and remotely-acquired imagery. Specific objectives include:

1. Determine the dependability of spatially-referenced data and simulation results in measuring or monitoring certain environmental parameters.
2. Evaluate the relationship between satellite-derived spectral transformations and key variables simulated by an ecological model (SPUR).
3. Demonstrate the utility of integrating spatially-referenced data and simulated processes for the monitoring of ecological processes.

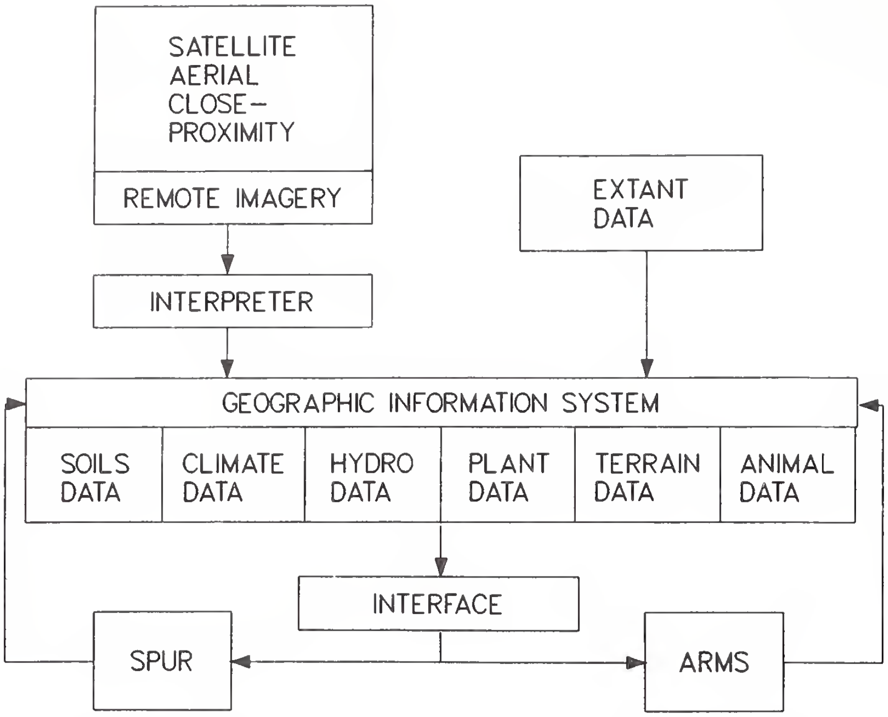

Figure 1. Diagram of a Geographically Reference Information Delivery System.

Phase II of GRIDS development will expand of the study area to include selected sites throughout the Central Great Plains region. This phase will test the ability of the system to emulate system processes across a wide range of ecological conditions.

The GRIDS package is a first step toward the development of a regional ecosystem monitoring and evaluation system. The incorporation of remote imagery and spatially registered information will expand the area of application, as well as increase the reliability of ecosystem simulation results. Including model results in a GIS will provide an excellent framework for spatially recording, displaying, and interpreting data. Further refinement of these technologies and the introduction of new technologies, such as linear programming models and Artificial Intelligence shells, will prompt the development of integrated decision support systems such as ARMS.

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A Management Tool for Rangeland Systems

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ABSTRACT

Ranchers are constantly faced with the problem of making decisions about future events while having very little information available as to the possible outcome of their decision. Tools must be developed that will assist ranchers in evaluating alternative management strategies. A collaborative research project by the USDA-ARS and Colorado State University was started in 1988 to develop an integrated decision support system designed to aid ranchers in optimizing ranch operation. The research area, methodology, and model structure are described in this paper.

INTRODUCTION

The ranching industry has traditionally been adversely affected by marketing and weather fluctuations, and in recent years many other issues have arisen to make planning and decision-making more complex. These new variables include exotic breeds of livestock, federal programs such as the Conservation Reserve Program (CRP), the possibility of increased grazing fees on public lands, and a host of environmental concerns such as water quality, disturbances of wildlife habitats, and soil erosion. New technologies will continue to be developed that provide even more options for producers. Ways must be found to evaluate this almost endless set of variables in a rational manner. Ranchers must be provided with the tools they need to find the best combination of practices for their land. In particular, they need a way to optimize their income for the short and mid-term, but at the same time ensure the conservation of their natural resources for future generations (Hanson 1989).

The Agricultural Resource Management System (ARMS) program is an integrated decision support system designed to aid ranchers in optimizing ranch operations. Two classes of models, a long-term rangeland simulation model and a short-term linear programming model (LPM), will be integrated via an expert system to form the ARMS program. In addition, ARMS will incorporate the expertise gained by interviewing potential users. Management recommendations will be based on three sources of information: short-term economic analysis (from the LPM), longer-term environmental consequences of the short-term decisions (using the rangeland model), and the knowledge and experience of established ranchers.

The purpose of this project is to develop a computer software package that will aid ranchers in making economically sound short-term management decisions that are consistent with long-term environmental conservation goals.

METHODOLOGY FOR ARMS DEVELOPMENT

The development of ARMS is a collaborative research project between Colorado State University and the USDA-ARS Great Plains System Research unit in Fort Collins, Colorado. Development of the program is divided into four phases. Phase one, cooperator identification and selection, began in the Spring of 1988 with the selection of a group of ranchers in southern Colorado. The ranchers selected are participants in the San Luis Valley Farming Systems Project (SLVFSP) which was established in 1983 by Colorado State University and the Cooperative Extension Service. The SLVFSP is an interdisciplinary systems research project targeted at agricultural improvement for limited resource farmers located in the south-west corner of the San Luis Valley. A relatively high proportion of the participants in the project area are Hispanic. Farms are generally smaller and less capitalized than those farms in the northern part of the valley. Agricultural practices in this area tend to involve less technological input (Eckert 1987).

The second phase, data collection, was completed during the summer of 1988. Field data pertaining to animal production, grazing, and cropping systems were collected. Concurrently, secondary data describing soils, range vegetation and condition, weather, economic conditions, and other variables needed to parameterize the simulation and linear programming models were collected.

The third phase of development is that of knowledge acquisition. This stage was begun in the summer of 1989. A target population was selected based upon the information collected during phase two. Interviews concerning individual management practices were conducted for the construction of the expert system shell of ARMS. The final phase is the integration of the model components, model application, and verification.

STUDY SITE DESCRIPTION

The research area is located in Conejos county of the San Luis Valley in South Central Colorado. The geographical boundaries of the project area are latitude 37° 22' 35" to 37° 15' 20" N and longitude 105° 57' 30" to 106° 12' 15" W. The climate in the valley is characterized by cold winters, lower than -17°C an average of 50 nights per year, and moderate summer temperatures, average maximum temperatures of 29°C and average minimum temperatures of 5°C. Precipitation is very light in both summer and winter. Light thunderstorms in the valley account for most of the precipitation, which averages 18 cm annually. Snowfall in the research area is less than 100 cm per year, but because of low temperatures, snow remains for several weeks.

The dominant soil of the prairie on the western edge of the project is a Dunul-Lamanga complex with Garita cobbly loam closer to the foothills. The dominant vegetation in this area consists of *Bouteloua gracilis*, *Sitanion hystrix*, *Aristida longiseta*, *Gutierrezia sarothrae*, *Chrysothamnus* spp. and *Artemisia* spp.

Agriculture in the project area is quite diverse. The principle crops are alfalfa, malting and feed barley, potatoes, oats, native grass hay, and small acreages of quinoa. Alfalfa is produced by all participants in the project area. All agricultural crops in the valley are irrigated because of the limited amount of rainfall. The predominant method of water application in the project area is flood irrigation. Other practices include both furrow and center pivot sprinkler irrigation. Most farms in the project area receive surface water from at least one of three rivers, the Alamosa River, the La Jara Creek, and Hot Creek. Several ditches and canals from these sources provide water access to various farms in the research area.

The primary livestock enterprises in the project area are cattle and sheep. Other livestock species in the area include swine, poultry, and horses. Most of the full time livestock producers in the research area depend on Forest Service and Bureau of Land Management permits for summer grazing of their animals. Most of the ranchers who have large numbers of sheep also depend upon the foothills and prairies in the western part of the project area for spring and winter grazing. Cattle producers typically graze their animals on pastures in the area prior to moving them to the mountains and after returning from summer range. Those producers who do not hold grazing permits utilize native grass pastures and meadows in the valley.

Although calving and lambing dates vary somewhat from ranch to ranch, the calving season is from February to June, while lambing occurs from mid-March to till mid-May. Intact males and non-pregnant females typically graze together on the summer range. Consequently, some offspring are born late in the production year.

MODEL CONSTRUCTION

The ARMS model (Fig. 1) consists of four major structures: two expert systems, a linear programming model, and a livestock-rangeland simulation model (Simulation of Production and Utilization of Rangelands).

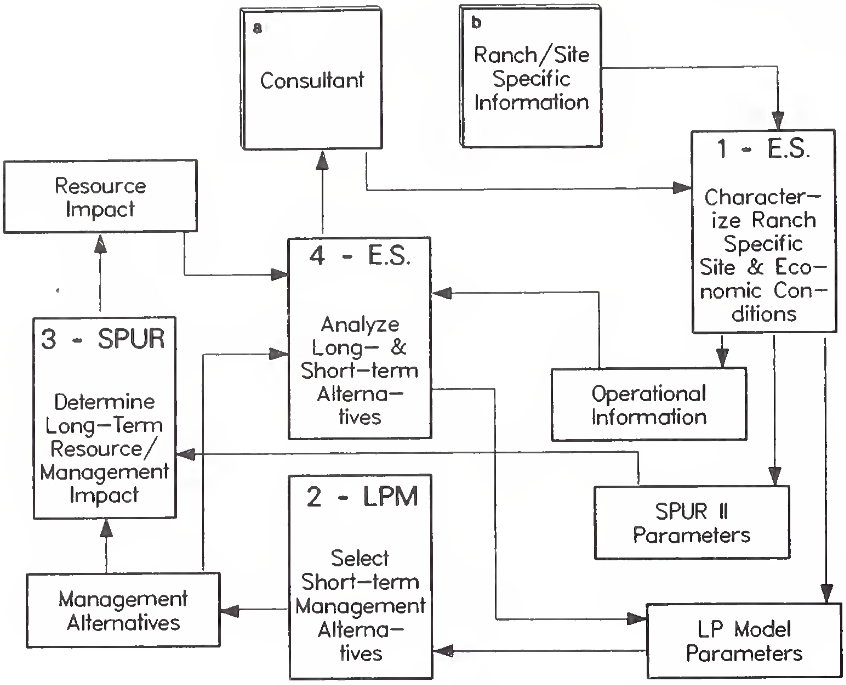

Figure 1. Diagram of the proposed ARMS decision support sytem.

Model Initiation

ARMS is designed to be a general model that can be transported from site to site. This design is made possible by the use of the front end expert system. The user will input ranch- and site-specific information. The information entered will be used to construct the data base needed to generate parameters for the simulation model, coefficients for the LPM, and operational information for the second expert system.

Operational information includes the goals and management practices of the rancher. The information is used to set ranch-specific rules to be used in the analysis module of the second, or core, expert system. The information for parameters and coefficients include topographical information, weather data, soil characteristics, information concerning range vegetation and condition, economic conditions, types of crops produced and acreage in production, species and number of livestock produced. This data is to be stored in a Geographical Information System (GIS) for graphical representation and future reference.

Linear Programming Model

The second model structure is a linear programming model. Several enterprises that are typical of the area will be preprogrammed into the model. Information gained from the front end system is used to trip switches needed to determine the "best" management scenario from a list of possible alternatives. Thus, the purpose of this module is to select the best set of short-term management alternatives by allocating the available resources. The objective is to maximize ranch profitability subject to the constraints defined by the consultant and rancher.

A major problem with linear programs are that they are static in nature. To solve this problem, coefficients are updated throughout the simulation. As conditions change and are re-evaluated. the coefficients are changed through a feedback from the simulation model and the second expert system.

Simulation Model

Management alternatives such as pasture utilization, number and species of livestock, irrigation. and fertilization, as determined by the LPM are evaluated by a rangeland simulation model. SPUR (Simulation of Production and Utilization of Rangeland) is a general grassland simulation model composed of five basic components: hydrology. plant growth, animals (domestic and wildlife), and economics. The model is driven by daily inputs of precipitation, maximum and minimum temperatures. solar radiation, and wind run. Further descriptions of SPUR can be found in the SPUR Documentation and Users Guide (USDA 1987). The purpose of SPUR is to determine the long-term, ecological consequences of the management decisions selected by the LPM. The effects of these decisions are assessed in terms of soil erosion, range production, and animal performance.

Analysis

The fourth structure is the second. or core. expert system. The purpose of this structure is to analyze the the short and long-term management alternatives and prepare reports for the end-user. Alternatives are compared with the goals and management practices of the manager. Recommendations and coefficients changes are made based upon the knowledge base that was collected in phase three of development.

DISCUSSION

Agroecosystems are complex systems comprised of both natural ecosystems such as grasslands and sometimes forested lands on one hand, and domesticated ecosystems such as croplands and pastures on the other hand. Unlike natural ecosystems, agroecosystems do not simply function as a result of internal checks and balances (Spedding 1984). Agricultural systems are managed by a manager who manipulates the system by a set of decisions that are, for the most part, directed by forces outside the system.

Most agricultural-system models have been either simulation models or optimization models (Hart 1984). ARMS is unique among agricultural system models in that the model is an integration of these two classes of models. In addition, ARMS uses the knowledge and expertise of ranchers. With ARMS we can investigate questions such as: What decisions do ranch managers make? How are the decisions made? What impact do the decisions have on short-term economic conditions of the ranch? How do the decisions affect the long-term sustainability of the ranch? What are the environmental consequences of the decisions made?

If new technology is to be adopted by farmers and ranchers, the technology offered must be consistent with the farmer's natural and economic circumstances (Winkelmann and Moscardi 1981). Gaining information about how and what decisions are made by farmers and ranchers is therefore of practical value for agricultural research and development. This information is also of theoretical value in identifying principles that can contribute to a general understanding of interactions in agroecosystems.

The decisions of farmers, particularly small farmers, concerning the adoption of new technology are influenced by their perception of risk (Shaner et al. 1982). ARMS can be used to reduce risk by evaluating the economic consequences of different management options. For example, the costs and expected returns of converting cropland into pasture, leasing pasture, or planting additional crops could be simulated by the model, thereby reducing the actual risk of planting.

Long-term effects of management options on the sustainability of the ranch could be evaluated. Sustainability can be defined as maintaining a specified level of production over long periods of time (Marten 1988). From the manager's perspective, level of production is determined by the number of animal units grazed on a certain pasture, tons of alfalfa harvested from a particular field, or even the level of income received from the current operation. From an ecological point of view, sustainability is expressed in terms of soil productivity under current use patterns, water quality near chemically treated fields, or wildlife-use patterns on public grazing lands. ARMS will provide a method for maximizing the manager's goals and objectives while minimizing the ecological degradation of available resources.

Finally, the system will provide the rancher with information that will enable him to better compete for borrowed funds. When completed, ARMS will be a powerful tool both to optimize ranching operations and to reduce the risk of making a wrong decision.

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A Rootzone Water Quality Model (RZWQM)

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DeCoursey, D.G. and K.W. Rojas. 1991. A rootzone water quality model (RZWQM). Pages 117-120 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

INTRODUCTION

The rootzone water quality model is a physical, chemical, and biological process model that simulates the movement of water, nutrients, and pesticides over and through the root zone of a representative point in a field. It is being developed by a group of ARS scientists (see below) in response to a request for simulation tools that can be used to study soil water and solute movement impacting groundwater quality. The physical processes simulated and degree of refinement included are a direct outgrowth of an interagency meeting held at the Pesticides Degradation Laboratory in Beltsville, Maryland in June 1986.

Initial development of the one dimensional model took place at a workshop in October 1986 at Pingree Park, Colorado. At that time the structure of the six major processes was identified. The processes and their authors are: physical processes (Laj Ahuja, Alan Hjelmfelt, Charles Hebson, Ken Rojas), nutrient processes (Marvin

Shaffer, Charles Hebson), soil chemistry (Marvin Shaffer), pesticide processes (Ralph Nash, Don Wauchope, Guye Willis, Les McDowell), plant growth (Jon Hanson, Allan Jones, Ken Rojas), and management (Jim Schepers, Walter Rawls, Ken Rojas).

At the present time all of the components have been coded and are interacting to produce a working model. The following discussion describes the status of each component, the testing and verification, and some features that may be included in future versions.

Physical Processes (Internal Hydraulics and Hydrology)

Physical processes include a large number of interrelated hydrologic processes. Items coded and verified include infiltration; chemical transport during infiltration; transfer of chemicals to runoff during rainfall; water and chemical flow through macropore channels and their absorption by the soil matrix; soil hydraulic properties estimation from bulk density and 1/3, or 1/10 bar water content; heat flow; potential evaporation from the soil and residue surfaces; potential transpiration; root water uptake and soil water redistribution; and chemical transport during redistribution. The hydrology component which simulates the surface runoff, erosion and sediment transport to and over a representative point in the field has not been coded; code from WEPP will be used for this purpose.

Soil Chemistry

Soil chemistry processes consist of the processes necessary to describe the soil inorganic chemical environment in support of nutrient and pesticide processes. The inorganic processes include bicarbonate buffering; dissolution and precipitation of calcium carbonate, gypsum, and aluminum hydroxide; ion exchange involving bases and aluminum; and solution chemistry of aluminum hydroxide. The chemical state of the soil is characterized by soil pH and solution concentrations of aluminum and other cations depending upon pH. This model is completely coded, operational, and tested against independent data sets.

Nutrient Processes

The nutrient processes define transformations of absorbed and soluble nutrients at all times. Given initial levels of organic matter, crop residue, and nutrient concentrations the submodel simulates the decomposition of soil organic matter and crop residues, the mineralization, nitrification, immobilization, denitrification, and volatilization of appropriate nitrogen and phosphorus species; and the adsorption/desorption processes of both phosphorus and nitrogen. Levels of soluble nutrients are used in estimating crop growth, nutrient extraction in surface runoff, and movement below the root zone. Surface adsorbed materials are subject to erosion. The nitrogen submodel has been coded and calibrated. Validation of the complex interactions have just begun. The model structure for phosphate processes is in place, but coding is not completed. Potassium, trace elements, and selenium chemistry will be added in future versions. The basic structure for these processes is in place; but the specific routines have not been developed.

Pesticide Processes

Pesticide processes consist of the processes necessary to estimate the transformation and degradation of pesticides (1) on the plant, crop residues, and soil surface and (2) in a given volume (layer) of soil on any given day. Depending upon the application site and given the plant, crop residue, soil and pesticide characteristics and environmental conditions; the model simulates the amount of pesticide reaching the soil surface and the amounts adsorbed and moving through each soil layer. In addition to a "lumped" dissipation, volatilization, photolysis, hydrolysis, biodegradation, oxidation, and complexation dissipation pathways are possible if data are available to drive them. At present only the lumped dissipation processes are coded, primarily because only lumped values are available for most pesticides. Equilibrium and kinetic adsorption/desorption isotherms are used to obtain a balance between adsorbed and solution pesticide phases.

Plant Growth Processes

The crop growth submodel describes crop growth to the extent that it estimates (1) specific yield of fruit, forage, or root crops; (2) soil cover conditions; (3) actual transpiration rates and soil zones from which water, nutrients, and pesticides are removed; (4) total dry mass of material grown (by plant parts) and its death or abscission; (5) the effects of water, nutrient, temperature, and pesticide stress; and (6) the amount of surface and standing material needed to estimate its impact on surface roughness. This submodel consists of two major components, production and colonization (plant stage of growth) subsystems. Coding for both subsystems is complete. The model is operational; however, performance of the root growth and plant-water-chemical balance is uncertain. Also the effect of pesticide translocation through the leaves and roots and its possible influence on growth remains to be coded.

Management Processes

The management submodel consists of a description of tillage and management processes defining the state of the root zone. It includes typical tillage practices for most common crop rotations and the impact these tillage practices have on surface roughness, erosivity, soil density, and micro and macroporosity. When not specified by the user, the timing of typical tillage practices (fertilizer and pesticide applications, irrigation and drainage, planting densities and timing, primary tillage cultivation, and harvest operations) are assumed functions of soil moisture and crop conditions. No till features are also included. At this time, coding is completed for irrigation, planting, cultivation, fertilizer and pesticide applications and primary tillage. Algorithms to describe soil bulk density reconsolidation and tillage mark degradation, as functions of time, rainfall, and additional tillage have been coded but may be modified to match code from the WEPP project.

Input Data Generator

The input data generator assembles data in the format needed by the six major processes. It is designed to call information from pesticide, soils, management, plant, nutrient, and soil chemistry data bases; and relies, when necessary, on default values. It interrogates the user for site specific information and provides help in the form of questions and tables. Default values are provided automatically when necessary. Several data bases are in place, but most are being expanded and adapted for RZWQM. The mechanism to access the data and coding of the input file manager are complete. Work remains on some of the help screens.

Output Report Generator

The output report generator interrogates the user to determine the output desired, then assembles the information into a report with an easy to read format. It includes routines to summarize the data into user defined periods such as daily, monthly, and yearly totals. It also displays the information in graphical form if desired. Use of the output report writer is facilitated by a series of "canned" output packages. These include one for each of the major processes supplemented with hydrologic and other data. There is also one general output that includes selected features from each component. If the user desires something different, a tailor-made selection is possible.

STATUS OF RZWQM AS A COMPLETE UNIT

The three major systems which make up the RZWQM package (input data file generator, simulation model and output report generator) are operational as described above and six data bases are being assembled for in-depth testing of RZWQM. The six data bases being developed are environmentally important case studies. They consist of corn and soybeans in the irrigated Platte River Valley in Nebraska, corn and soybeans in Iowa, cotton in the coastal plains of Georgia, and cotton in the San Joaquin Valley of California. The model accepts data files from the input data file generator; processes the data and generates tabular and graphical output files. The input data file generator is essentially complete except for improvements in user interaction and data bases. The submodel processes are essentially complete and the output report generation is complete. A draft version of the simulation model is currently undergoing extensive testing of component interaction as a whole. As new improvements are included they will go through the same series of rigorous testing that have been used previously to insure model cohesiveness and validity. Working versions of the complete model are being used by team members; updates are being distributed periodically.

Computer Systems

Code for the simulation model conforms completely to ANSI-FORTRAN-77 programming standards and limitations. The Input Data Generator and Output Report Generator programs are designed specifically for use on an IBM-compatible microcomputer system. The model has been coded simultaneously for use on a 386 PC and a mini system such as a DEC Micro Vax II.

Simulation of the Corn Rootworm/Corn System with Emphasis on Improved Pest Mangement

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Naranjo, S.E. 1991. Simulation of the corn rootworm/corn system, with emphasis on improved pest management. Pages 121-130 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

INTRODUCTION

Corn rootworms, *Diabrotica* spp., are considered important pests of corn throughout the corn-growing regions of the Great Plains. Larvae inhabit the soil and feed on the roots of corn. This feeding impacts yield by causing physiological stress to the plant and by promoting lodging. In the United States, the combined annual cost of insecticides for pest suppression and value of crop loss due to larval feeding exceeds one-billion dollars (Metcalf 1986). This estimate does not include external costs of environmental degradation and health risks associated with the application of the highly toxic, broad-spectrum pesticides used for corn rootworm suppression.

Management strategies that reduce the impact of corn rootworm damage and promote sustained corn production are possible. However, such strategies must be based on an understanding of the functioning of the entire agroecosystem. Design of sustainable agricultural systems that include corn will depend on the combined effort of researchers from many disciplines. Mathematical modelling and simulation will play a central role in this effort. Models will provide a framework for synthesizing research information, formulating working hypotheses, and evaluating crop production systems. Models of pest population dynamics will form an important part of larger models describing entire agroecosystems.

Some effort has been devoted to developing population dynamics models for insect pests of corn (e.g. Stinner et al. 1974, Mooney and Turpin 1976, Pontius et al. 1984, Onstad 1988). This paper describes a population model for *Diabrotica barberi*, the northern corn rootworm. The model is structured to allow direct connection between insect dynamics and crop development and, thus, may be easily linked with more extensive crop simulation models. First, the general life cycle and some of the unique features of the interaction between *D. barberi* and corn are described. A process-oriented population model is then briefly described and the model is then used to explore the impact of crop phenology on beetle population dynamics and to determine the potential value of manipulating crop development for reducing corn rootworm damage and pesticide usage.

SYSTEM FEATURES

Northern corn rootworms are univoltine or semivoltine and as larvae are functionally monophagous on the roots of corn. Larvae mature and adults begin to emerge from the soil in mid-summer at about the time that corn starts to flower. Emergence typically continues into early fall. Adults feed on the silks and pollen of corn, but may disperse widely to feed on the pollen of a variety of other flowering plants. Females oviposit in the soil from late July until early October throughout most of their geographic range. The eggs undergo diapause for one or more winters and hatch the following spring. Details of life history and biology are given in Chiang (1973) and Krysan (1986). Because of the life cycle of corn rootworms and the constraints of monophagy in the larval stage, these insects are most often pests in fields that have been in corn at least two seasons. Larval population size and damage potential one year is directly related to the abundance and ovipositional activity of female beetles the previous year. Consequently, the decision to suppress larval populations in a given field through the planting-time application of a soil insecticide is typically based on experience, aversion to the risk of crop damage, or, if available, on information about adult population levels gathered 9-10 months earlier.

The host plant, corn, plays a key role in the population dynamics of *D. barberi* (Hill and Mayo 1980, Branson and Krysan 1981, Naranjo and Sawyer 1988a). As a consequence, this insect demonstrates a high degree of temporal coincidence with corn. Egg diapause synchronizes larval hatch and development with corn roots between seasons, and the timing of various population processes synchronizes the adult with the flowering stage of corn within a season (Naranjo and Sawyer 1988a). This within-season synchrony of adult beetles with corn flowers is a striking feature of this system as it allows efficient exploitation of the brief occurrence of a high-quality food resource. Synchrony is maintained despite temporal shifts in crop phenology that may occur through changes in planting dates and cultivar selection.

However, seasonal population structure is dramatically affected by shifts in the timing of flowering (Fig. 1). In Figure 1 the horizontal bars represent the period of time during which more than 5% of the corn was in flower; hatched areas within bars the period of pollen shed. Curve bounding the open area represents total beetle density; open areas represent male component, stippled areas represent immature females component and dark areas represent mature females. Field labels indicate the cultivar used and the relative time of planting. As flowering is progressively delayed in a field, beetle population becomes increasingly dominated by mature, egg-laying females. As a result, total oviposition by a given population of beetles increases in fields that flower later in the season. The importance of crop phenology on the dynamics of this pest may offer avenues for insect population management based on the cultural manipulation of crop phenology rather than pest control based primarily on use of soil insecticides.

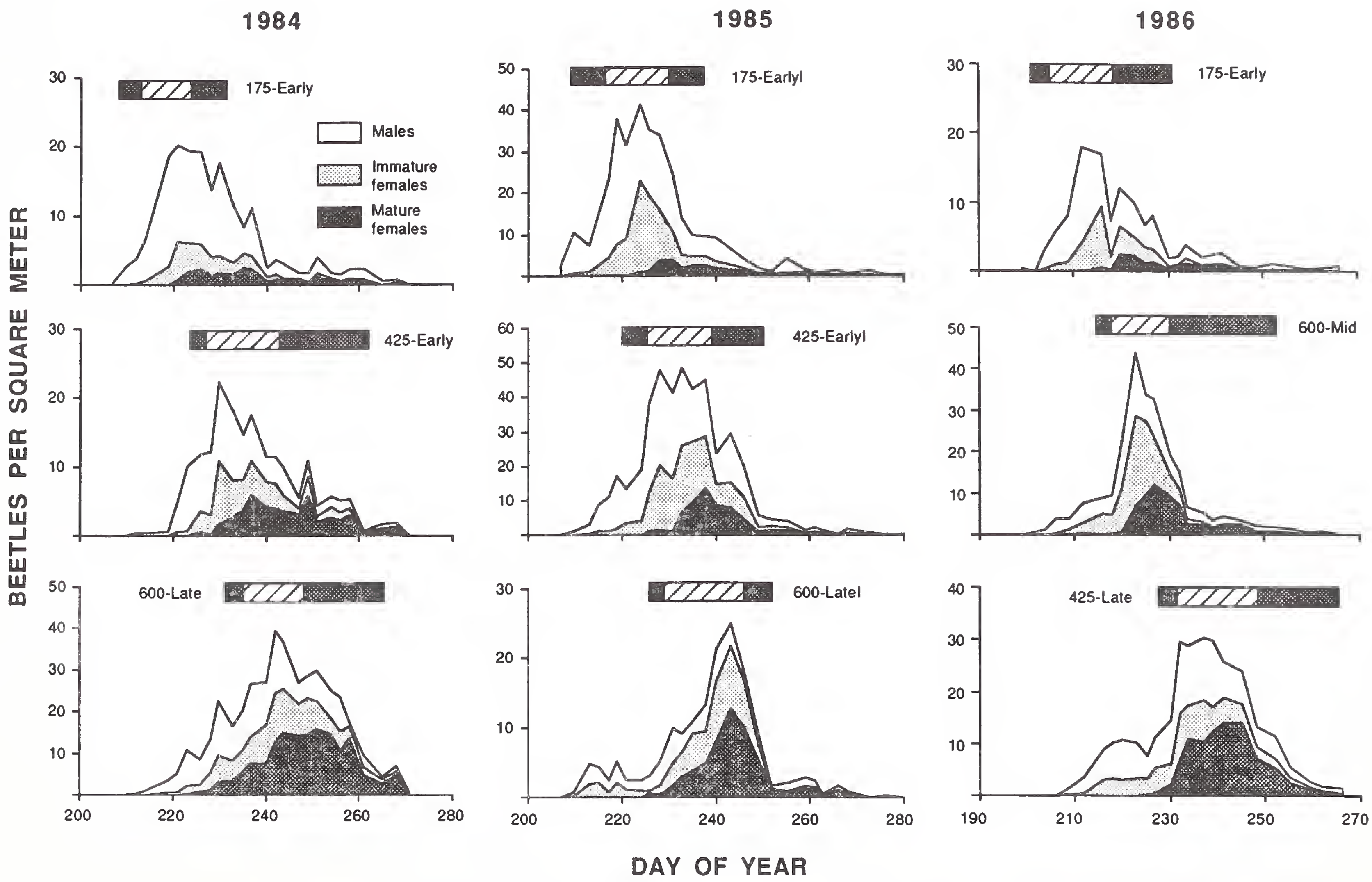

Figure 1. Observed beetle population density and composition in cornfields flowering at different times through the season. See text for a description. (Reproduced with permission of Environmental Entomology).

The model presented in the following section describes the influence of crop phenology on the population dynamics of *D. barberi* by explicitly modelling the relationships between corn phenology and the processes governing insect abundance in a specific field. The key issue here is to understand the factors determining the deposition of eggs in a specific field, and thus, the damage potential from larval feeding if corn is planted in the same site the following season. Therefore, the model focuses on adult beetles and does not explicitly describe the development, survival, and feeding of the immature stages (eggs and larvae).

SYSTEM MODEL

Relevant population processes for adult beetles can be summarized as emergence, mortality, dispersal, reproductive development, and oviposition. The system model incorporates submodels for each of these processes, many of which are directly influenced by corn phenology (Fig. 2). The basis of the model is a cohort-structured phenology model which incorporates variation in developmental rates between individuals and allows the maintenance of an age-structure in the female population (Naranjo and Sawyer 1988b). Adult recruitment is achieved by simulating the emergence of each sex over the season as a function of temperature, planting date, and cultivar. This submodel accounts for development of all immature stages including eggs which are assumed to begin accumulating developmental time when soil temperatures (5 cm) exceed 10°C anytime after 1 March (termination of diapause). Upon emergence, females pass through three developmental stages: prereproductive, reproductive and postreproductive. with the time spent in each stage being a distributed variable that is dependent on temperature. While in the reproductive stage, females oviposit at an age-specific rate that is temperature-dependent. Mortality and net dispersal (emigration-immigration) account for population attrition and both are functions of crop phenology which is explicitly modelled as a stochastic temperature-dependent process. Rates of mortality and net dispersal are lowest at the time of peak flower (period in time when the greatest proportion of corn plants are flowering) and greatest when no flowers are present.

The model predicts cumulative emergence, daily densities of adult beetles, age-structure, oviposition and plant development, and is initiated by specifying weather data, the cultivar and planting date of the field on physiological scales, and the total number of beetles that will emerge over the growing season. A complete and detailed description of model equations, parameter estimation and model operation can be found in Naranjo and Sawyer (1989).

To date various component submodels and the overall system model have been compared to independent data collected from two sites over a 2-year period, comprising eight fields (Naranjo and Sawyer 1989). Based on these comparisons, the model appears to incorporate the essential features of this insect/plant system and faithfully describes the dynamic behavior of the real system. The model has not been tested over a wide geographic range.

SYSTEM ANALYSIS

In developing cropping practices that reduce the number of external inputs and promote system sustainability, cultural factors such as planting date, cultivar selection, tillage and crop rotation schemes play an important role. Given the close

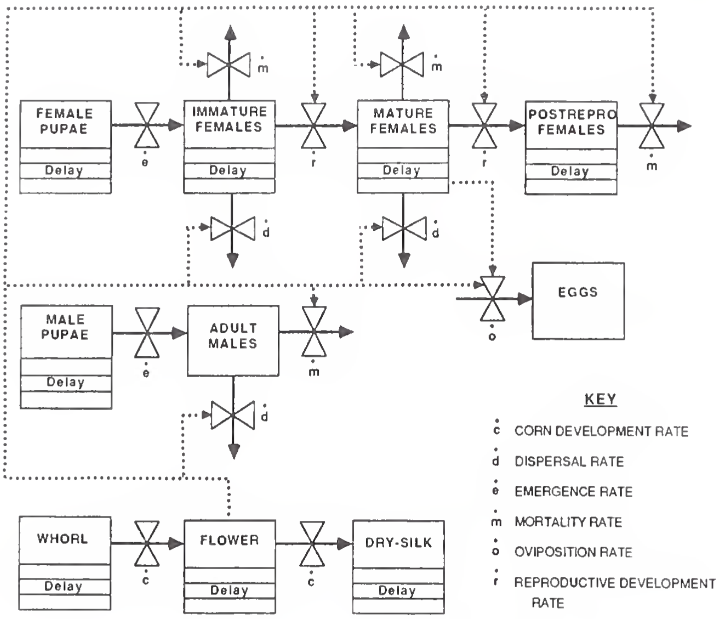

Figure 2. Relational flow diagram of the corn rootworm/corn system model. (Reproduced with permission from the Canadian Entomologist).

association between *D. barberi* and its host plant, any factor that influences the temporal or spatial features of the crop will have a direct effect on pest population dynamics. Rotation of corn with non-host crops, particularly rotations where corn is present only every 3-4 years, would clearly be an effective means of eliminating or reducing the corn rootworm problem. Tillage may also influence pest population dynamics by altering the subterranean environment of the larval stage (see Gustin et al. this proceedings). The manipulation of crop phenology, through alteration of planting date and cultivar selection, to reduce egg deposition and, thus, subsequent damage in a given field, may also represent a feasible management tool worthy of consideration. Results presented here demonstrate the impact of corn phenology on the population dynamics of *D. barberi.*

Figure 3 presents the results of analyses to examine the sensitivity of system behavior to changes in model parameters describing corn phenology. The standard simulation against which these changes were evaluated utilized a typical early-planted, mid-season cultivar and a 30-year average temperature data set. Total oviposition and the mean daily rate of oviposition per adult beetle over the season were used to gauge changes in system behavior. In most instances a 10% change in the value of a model parameter altered model output by over 10%. By far, the parameters with the greatest impact were those defining the developmental transition from flowering to post-flowering plants and those defining the overall period of flower availability (Fig. 3). Changes in the parameter defining the transition from pre-flowering to flowering plants had relatively little influence on system behavior. This suggests that factors which alter crop phenology later in the season are more critical. These analyses demonstrate that despite the close synchrony between adult beetles and flowering corn, temporal shifts in crop phenology have a significant and predictable impact on population structure and resultant oviposition.

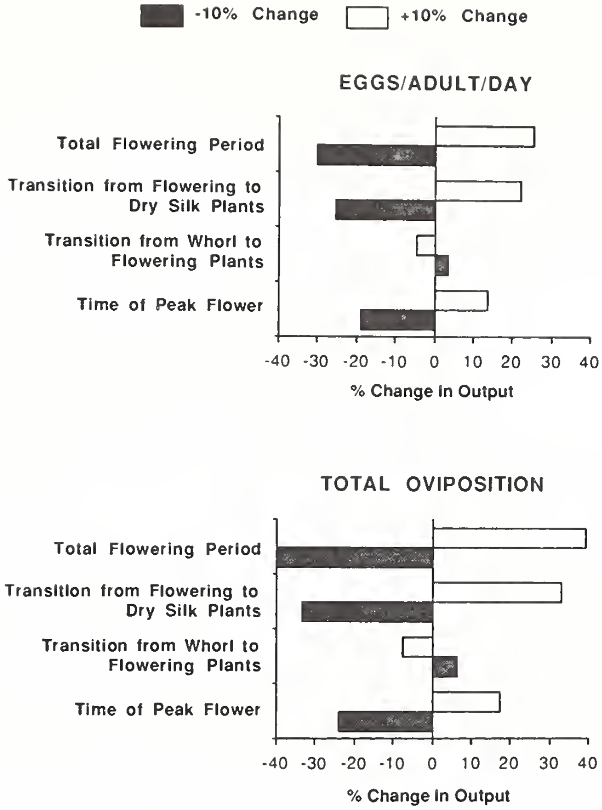

Figure 3. Sensitivity of model behavior to changes in model parameters describing corn plant phenology. Sensitivity is reported as the percentage change in model output for the indicated percentage change in model parameters.

Other analyses were performed to evaluate the interactions of various factors that might be used to alter crop phenology. A factorial sensitivity analysis was conducted with three levels of each of three factors: planting date, cultivar, and the overall period of flowering. Results demonstrated that interaction terms explained relatively little (<10% in any case) of the variation in system output (Fig. 4). Furthermore, there was little difference in the amount of variation explained by the three main factors. This suggests that it makes little difference which single cultural factor is manipulated. Planting early, using a short season (early flowering) cultivar, or a cultivar with a short flowering period will all decrease egg deposition in a field by roughly equivalent amounts.

Selection of the best practical combination of cultural factors to manipulate is problematic. Theoretically, the best strategy for minimizing oviposition in a specific field is to plant an early-season, short-flowering cultivar early in the season. However, the particular strategy employed will, in reality, depend on geographical, agronomic, and economic considerations beyond the scope of this analysis. For instance, the selection of a cultivar may be more influenced by the desire for certain agronomic characteristics, such as drought tolerance, that have little to do with timing and duration of flowering. Likewise, it may not be feasible to plant full-season hybrids or delay planting in areas with short growing seasons. Contrarily, it may not be desirable to plant a short-season cultivar that fails to use the full growing season. Compounding the problem is the impact of environmental variation, particularly seasonal temperature patterns (see below), which influence both insect and plant processes.

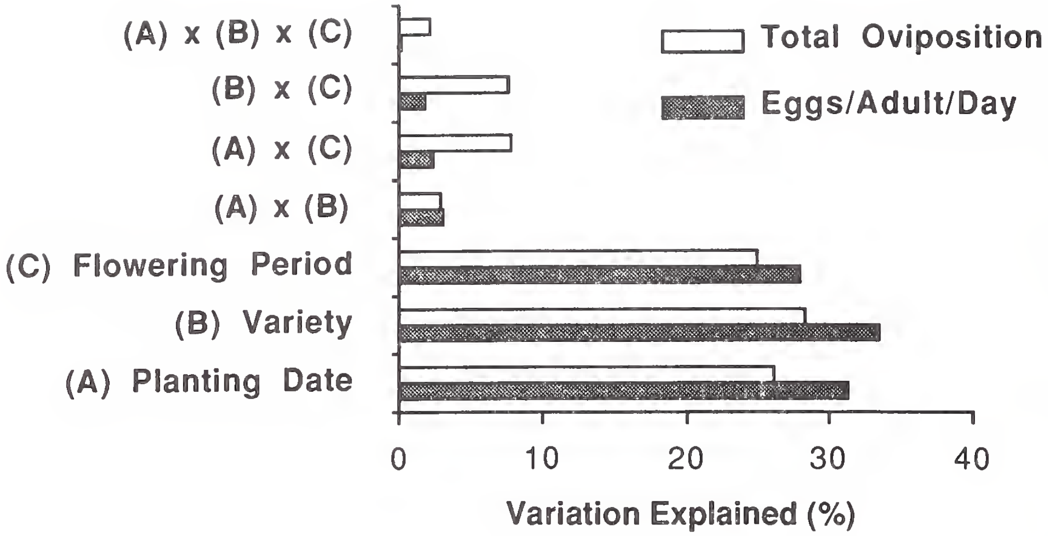

Figure 4. Simultaneous analysis of the effect of three levels of each of three factors influencing crop phenology on model behavior. Results are reported as the percentage of variation in model output explained by changes in each factor or factor interaction.

A final analysis was conducted to determine the impact of environmental variation (temperature) on beetle dynamics and to highlight the importance of observations of crop phenology in the decision-making process for pest suppression. Simulation was used to generate the response surfaces that depict the relationship between adult abundance and oviposition as a function of planting date, cultivar and seasonal temperature pattern (Fig. 5). These surfaces provide clear evidence of the dynamic nature of the relationship between adult abundance and oviposition.

As noted earlier, if the information is available, the decision to apply soil insecticides in continuous corn is usually made on the basis of adult population densities the previous season. Unfortunately, the relationship between adult abundance and damage potential is poorly understood (Foster et al. 1986). The response surfaces in Figure 5 indicate at least one component that is not presently involved in this decision process, the dynamic nature of egg deposition in response to changing crop phenology and temperature. If this information were considered, it might improve the efficiency of the decision process by eliminating the application of insecticides in cases where they are unnecessary. For example, because there is less oviposition per beetle in earlier-planted, earlier-flowering fields, a higher density of adult beetles would be needed to trigger the action for insect suppression. The opposite would be true for later-planted, later-flowering fields.

CONCLUSIONS

The development of cropping systems which require fewer external inputs and utilize the inherent properties of the crops and environment will require the combined effort of researchers from many disciplines. Pest control and management will form

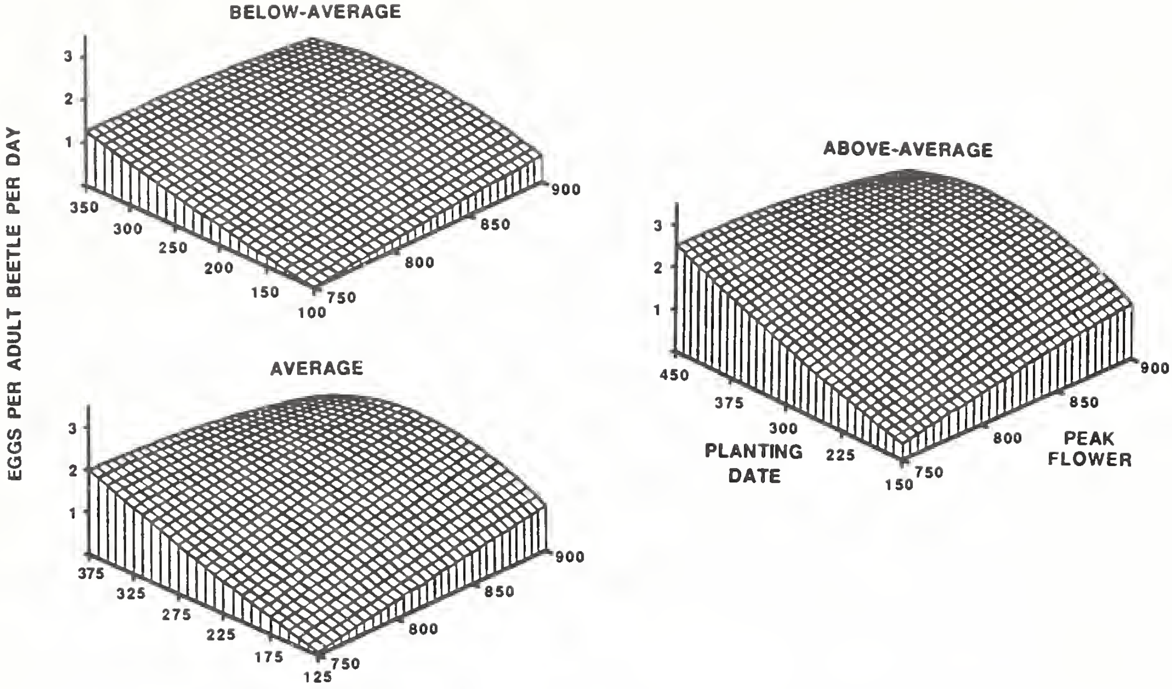

Figure 5. Simulation generated response surfaces depicting the relationship between adult abundance and oviposition (eggs/adult beetle/day) as a function of planting date, cultivar, and temperature. (Reproduced with permission from the Canadian Entomologist).

a integral part of the effort. As large-scale agroecosystem models are developed, it will be essential to include pest population dynamics models to more fully understand these systems and devise practical cropping systems. The model described and analyzed here could be easily incorporated into existing or evolving crop simulation models due to its explicit recognition of the insect/host plant interface.

Results of model analyses emphasize the critical importance of crop phenology to the population dynamics of *D. barberi* and its potential importance in the management of this serious pest. Manipulation of planting dates and cultivar selection, either individually or in combination, represent a powerful set of means for reducing site-specific oviposition. Along with agronomic and economic considerations, these cultural manipulations and an understanding of their impact on pest population dynamics could represent important tactics towards developing more sustainable cropping systems which de-emphasize the input of insecticides for pest suppression.

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Simulating Low-Input Cropping Systems with Computer Models

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ABSTRACT

Low-input cropping systems are being used more often as farmers are increasingly concerned with making a living, maintaining family health, and preserving the environment. Computer models are needed to help understand the principles involved in low-input cropping and to aid in designing new cropping systems. We have tried some existing computer models to determine whether they can successfully simulate low-input cropping systems and whether model modifications are needed. Low-input cropping systems used at the Rodale Research Center in eastern Pennsylvania are based on rotations of small grains, forage legumes, corn (*Zea mays* L.), and soybeans [*Glycine max* (L.) Merr.]. Often a second crop is planted before the first crop is harvested, resulting in multiple crops growing the same field at the same time. Fertility and soil tilth are maintained through organic amendments of green manures, plant residues, and/or animal manures. Most models developed for "conventional" cropping systems cannot handle large and diverse applications of organic

amendments, multiple cropping, or weeds and other pests. The effects of microbes and larger soil fauna on organic matter decomposition and nutrient cycling are not adequately modelled. Routines for simulating overwinter, rotation, and two-dimensional effects are not well developed. All of these components should be considered when older models are modified and new models developed.

INTRODUCTION

In recent years, low-input agricultural systems are being used more often as alternatives to conventional, chemically-based systems. Concerns for the environment (Hallberg 1986, Hallberg 1987, Myers 1985), pesticide safety on the farm and in the market place (Pimentel et al. 1980, Tangley 1986), and the increasing costs of pesticides and fertilizers (Lockeretz and Wernick 1983) have accelerated this movement.

Low-input cropping systems are designed to maximize the use of internal resources produced on the farm (animal manures, legume plow-downs, plant residues, etc.) while minimizing the use of external resources (synthetic fertilizers, pesticides, etc.) which must be purchased. Diverse crop rotations are the basis for most low-input cropping systems. Rotations which include legumes help maintain soil nitrogen and organic matter levels (Radke et al. 1988, Power and Doran 1984, Rennie 1982). Rotations also play an important role in the control of weeds, insects, and diseases (Liebhardt et al. 1989, Worsham and White 1987, Byers and Stromberg 1987).

The Rodale Research Center in eastern Pennsylvania has been experimenting with various low-input cropping systems for over ten years. A conversion experiment to study the effects of switching from a conventional system to a low-input system was initiated in 1981. The experiment consisted of two low-input cropping systems, each with five-year rotations, and a conventional corn (*Zea mays* L.)—soybean [*Glycine max* (L.) Merr.] cropping system (Table 1). This experiment is further described by Radke et al. (1987) and Liebhardt et al. (1989). A follow-up experiment begun in 1986 had similar treatments (Table 2), but added multiple cropping techniques to increase the economic returns from the low-input, cash-grain system (Radke et al. 1988).

We have been attempting to simulate some of the low-input cropping systems at the Rodale Research Center using computer models. Several existing computer models are capable of simulating many important soil physical and chemical processes and the growth of a given crop species. Such models usually were developed with conventional farming practices in mind and do not consider some factors important in low-input cropping systems. For example, few soil/crop models deal with weeds, insects, or diseases because the farmer is expected to apply the proper pesticides so they will not be a problem. Most models can handle nutrient additions from synthetic fertilizers but have difficulty simulating the fate of large additions of organic matter and/or animal manures. Therefore there are several additional requirements for modelling many low-input cropping systems. While there are some models that can handle one or more of the requirements we mention below, there are presently none, that we know of, that can handle all or most of them. We looked at several models including NTRM (Nitrogen-Tillage-Residue-Management; Shaffer and Larson 1987), EPIC (Erosion/Productivity Impact Calculator; Williams and

Renard 1985). NCSWAP (Nitrogen and Carbon cycling in Soil, Water and Plant; Clay et al. 1985) and the Century Carbon model (Parton et al. 1987, Parton et al. 1988). We chose the NTRM model for most of our work because it simulates several crops, carbon and nitrogen transformations, tillage, and residue amendments. However, the version of NTRM that we started with could not meet the additional requirements for modelling low-input cropping systems that we discuss below.

Table 1. Rotation sequences for the five-year Rodale Research Center Conversion Experiment. Each of the three systems has three entry points into the rotations.

	Year				
TRT	1981	1982	1983	1984	1985
			Low-input with animals, System 1		
1-1	Spring Oat Red Clover	Red Clover	(Manure) Corn	Soybean	(Manure) Corn Silage
1-2	Corn	Soybean	(Manure) Corn Silage	Wheat Red Clover[1]	Red clover
1-3	(Manure) Corn Silage	Wheat Red Clover[1]	Red Clover	(Manure) Corn	Soybean
			Low-input cash-grain, System 2		
2-1	Spring Oat Red Clover	Corn	Spring Oat Red Clover	Corn	Soybean
2-2	Soybean	Spring Oat Red Clover	Corn	Wheat Hairy Vetch	Corn
2-3	Corn	Soybean	Spring Oat Red Clover	Corn	Spring Oat Red Clover
			Conventional cash grain, System 3 - Control		
3-1	Corn	Corn	Soybean	Corn	Soybean
3-2	Soybean	Corn	Corn	Soybean	Corn
3-3	Corn	Soybean	Corn	Corn	Soybean

[1] *Overseeding*

Table 2. Rotation sequences for the five-year Rodale Research Center Farming Systems Experiment. Each of the three systems has three entry points into the rotations. RC-Alfalfa is a red clover, alfalfa mixture and Corn (SS) is short-season corn.

	Year				
TMT	1986	1987	1988	1989	1990
Low-input with animals, System 1					
1-1	Wheat RC-Alfalfa[1]	RC-Alfalfa	(Manure) Corn	Soybean	(Manure) Corn Silage
1-2	(Manure) Corn	Soybean	(Manure) Corn Silage	Win. Wheat[2] RC-Alfalfa[1]	RC-Alfalfa
1-3	(Manure) Corn Silage Win. Wheat	Win. Wheat RC-Alfalfa[1]	RC-Alfalfa	(Manure) Corn	Soybean
Low-input cash-grain, System 2					
2-1	Oat RC-Alfalfa	Corn	Spr. Barley[3] Soybean Win. Wheat[1]	Win. Wheat RC-Alfalfa[1]	Corn (SS) Win. Wheat
2-2	Spr. Barley Soybean Win. Wheat[1]	Win. Wheat RC-Alfalfa[1]	Corn	Spr. Barley Soybean Win. Wheat[1]	Win. Wheat RC-Alfalfa
2-3	Corn (SS) Win. Wheat	Win. Wheat Soybean Win. Wheat[1]	Win. Wheat RC-Alfalfa[1]	Corn	Spr. Barley Soybean
Conventional cash grain, System 3 - Control					
3-1	Corn	Corn	Soybean	Corn	Soybean
3-2	Soybean	Corn	Corn	Soybean	Corn
3-3	Corn	Soybean	Corn	Corn	Soybean

[1] *Overseeding*
[2] *Winter Wheat*
[3] *Spring Barley*

Modelling Considerations for Low-Input Systems

Modelling the low-input cropping systems used at the Rodale Research Center demonstrated several deficiencies in the model we were using. NTRM often underestimated growth and yields on the low-input corn crops that received only animal or green manures (Fig. 1). The model was not making the nitrogen from these sources (up to 180 kg-N/ha) available to the plants quickly enough. We could trick the model by saying that some of the organic amendments were actually nitrate or ammonium fertilizer, but we shouldn't have to resort to this. Other things, such as multiple cropping, couldn't be handled by the model at all. In other cases, the model's treatment of the factor was inadequate, e.g. microbial effects are approximated from soil temperature and soil water contents without actually simulating microbial biomass and activity.

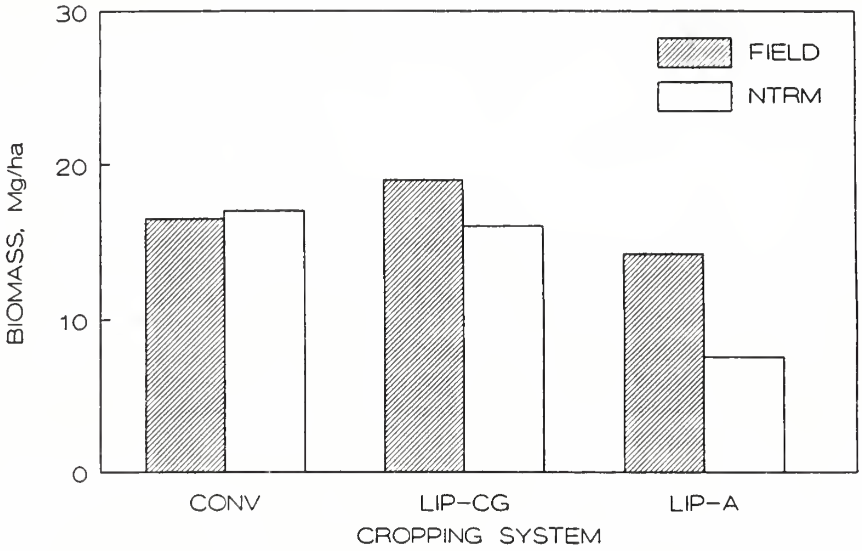

Figure 1. Corn biomass measured in the field and simulated with the Nitrogen-Tillage-Residue Management (NTRM) Model for the conventional (CONV), low-input cash-grain (LIP-CG) and low-input with animals (LIP-A) cropping systems in the Conversion Experiment at the Rodale Research Center in 1985.

The following six factors should be incorporated into all models to be used with low-input cropping systems:

1. Organic amendments
2. Microbiology and soil fauna
3. Multiple cropping
4. Weeds and other pests
5. Overwinter and rotation effects
6. Two- and three-dimensional effects.

We consider the first four items to be necessary and the remaining two to be desirable for certain cropping practices. Each item is discussed briefly.

Organic Amendments

Low-input cropping systems often return relatively large amounts of organic matter to the soil from crop residues, green manure plow-downs, or animal manures (with more or less bedding). The breakdown of this material depends on the makeup of the amendment (C/N ratio, lignin content, etc.), the degree of incorporation into the soil, the soil temperature and soil water content, and the microbial activity associated with decomposition and nutrient transformations. While several models have subroutines to deal with organic matter additions, they seldom handle large and diverse additions adequately—especially over the duration of the complete rotation.

Microbiology and Soil Fauna

Soil is a dynamic, living medium. This is especially important for low-input cropping systems which depend on a healthy and fertile soil environment. Microbes and other soil fauna are instrumental in the decomposition of organic matter in the soil and play an important role in the availability of nutrients, especially nitrogen. Soil animals cause channeling and mixing of the soil and organic matter which effects changes in the soil's physical and chemical properties. For example, soil structure, aggregate stability, and infiltration rates (Fig. 2) are changed by soil faunae activity.

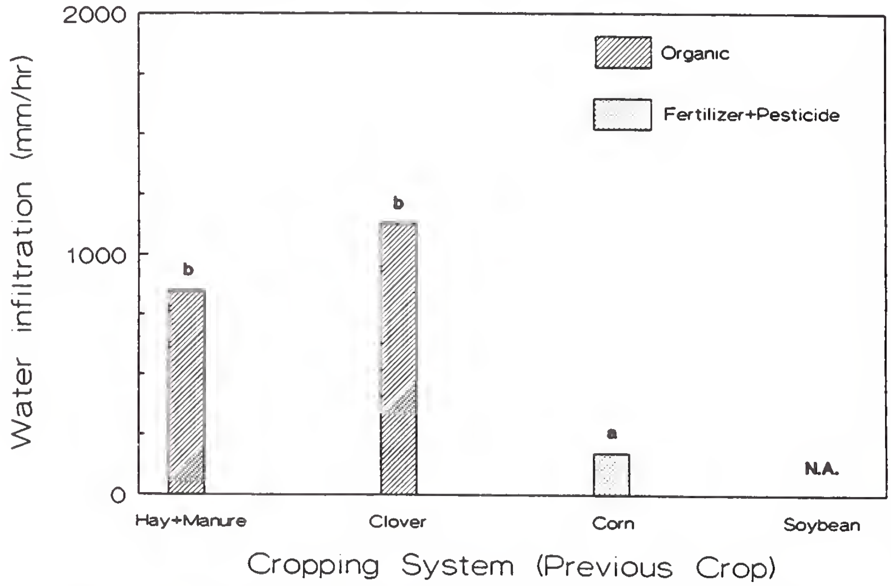

Figure 2. Water infiltration rates into corn plots with various preceding crops in the 1988 Rodale Research Center Farming Systems Experiment.

Multiple Cropping

Growing more than one crop at a time is common in many low-input cropping rotations. Using a small grain as a nurse crop for a legume hay has been a long-time practice. More recently, overseeding and interseeding techniques have been developed for keeping continuous cover on the field to combat erosion and weeds. Interseeding soybeans into a small grain at the pre-boot stage has proved successful where there is sufficient rainfall. Overseeding a legume into corn or soybeans before harvest provides a fall catch or cover crop and can be used for a hay or a green manure crop the following year. Two or more crops growing in the same field at the same time compete for nutrients, soil water, space, and light. Interaction between crop species adds even more complexity to the system. These factors must be modelled if we are to adequately simulate multiple cropping situations.

Weeds and Other Pests

Weeds, insects, and diseases can never be completely eliminated from cropping systems. This is true even with the extensive use of chemicals. Pests in low-input cropping systems often are managed only with cultural and biological methods. The effects of pests on crop growth and yields need to be considered as well as the influence of various management techniques on pest control. Pests must reach some threshold level before yield reductions occur. This level will depend on climatic, soil, and crop conditions. A higher threshold must be reached before economic losses are sustained, i.e. some yield loss can occur before it is profitable to apply pest control. Such complex interactions need to be modelled. Weeds can probably be handled as one or more additional crops that compete and interact with the real crop plants.

Overwinter and Rotation Effects

Many crops grown in low-input cropping systems are expected to overwinter. Winter wheat, winter barley, and legume cover crops planted in the fall continue to grow the following spring. Moreover, all processes do not stop during the winter, even when the soil is frozen. The processes of freezing, thawing, and evaporation cause changes in physical and chemical conditions. For example, water moves towards a frozen layer and may cause the movement of nutrients as well. Evaporation from the soil may leave salt residues at or near the surface. Snow cover provides thermal insulation during the winter, but melts in the spring either to run off, evaporate, or infiltrate into the soil. These processes may be important in the overall system and need to be considered in models designed to simulate rotational cropping systems throughout the complete rotation. Rotational effects on yields are important. Corn yields were often less when the preceding crop was corn rather than a different crop (Fig. 3). Similar results have been noted for other cropping sequences. More than simple nutrient status is involved in these differences. Interactions with disease organisms, allelopathy, or other factors may be involved.

Two- and Three-Dimensional Effects

Some cropping systems use management practices that may require two- or three-dimensional models to spatially simulate the real field situation. Ridge tillage, for example, would need at least a two-dimensional model to predict temperature, water contents, and root growth at given locations within the ridge. Fertilizer banding is

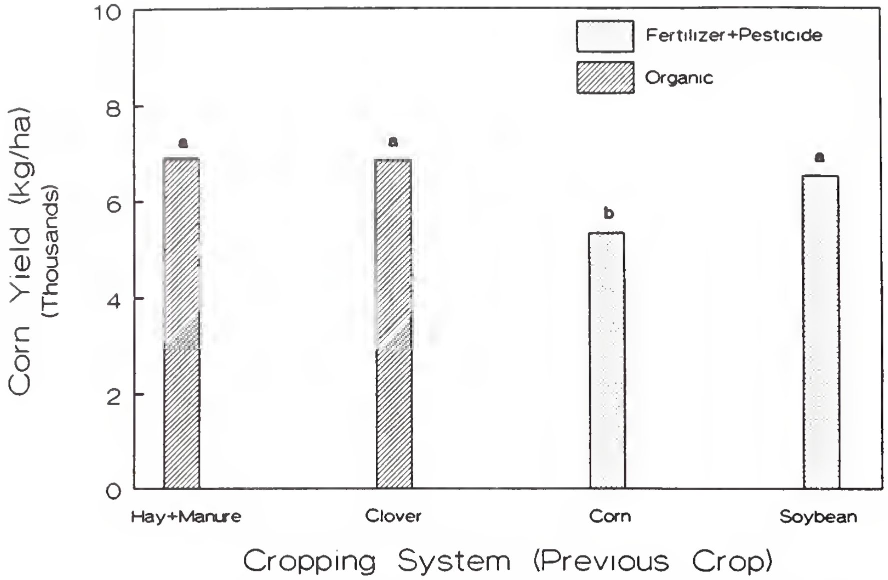

Figure 3. Corn yields following various crops in the Farming Systems Experiment at the Rodale Research Center in 1988.

another example where a two-dimensional model could be useful. While all low-input cropping systems may not require more than a one-dimensional model, multi-dimensional models are desirable in cases where large horizontal gradients play an important role in physical, chemical, or biological processes.

SUMMARY

Some cropping systems are difficult to simulate with models developed for "conventional" cropping systems. This is particularly true for low-input cropping systems that rely on complex cropping rotations, biological and cultural control of pests, and nutrient sufficiency through the use of legumes, animal manures, and the cycling of nutrients within the system. All crops in a cropping rotation need to be modelled throughout the entire rotation with proper consideration of all of the important factors. Biological factors are as important as the physical and chemical factors and need to be treated as such. All components of a cropping system need to be considered when older models are modified and new models are developed. NTRM is presently being modified to simulate many of the factors mentioned above.

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Corn and Redroot Pigweed Interactions as a Function of Water, Nitrogen, and Light

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ABSTRACT

Increased emphasis on low-input and sustainable agricultural production systems has demonstrated a need to simulate crop-weed competition under a range of climate, soil, and management conditions. A field study was initiated to provide information and data to help develop a crop-weed interaction subprogram for the NTRM simulation model. Interactions between redroot pigweed (*Amaranthus retroflexus* L.) and corn (*Zea mays* L. var. Pioneer 3906) were evaluated during the 1987 and 1988 growing seasons. Treatments consisted of various combinations of irrigation, fertilization, corn population levels, and redroot pigweed population levels. Competition for water and nitrogen restricted dry matter accumulation of both redroot pigweed and corn in mixtures. As soil water availability decreased in mixed stands, the percentage of total dry matter shifted downward for corn and upward for redroot pigweed. Nitrogen deficits in mixed stands shifted the percentage of total dry matter upward for corn and downward for redroot pigweed. Light interception was greatest in mixed canopies receiving irrigation and fertilization. Corn monocultures intercepted more light higher in the canopy than mixed stands under water or nitrogen deficit conditions.

INTRODUCTION

Crop models use climate. soils, and crop history data together with management information as inputs to predict crop growth and yield. Only a few of these models have been designed to incorporate a weed interference component to simulate competitive influences on crop growth (Baeumer and de Wit 1968, Scott et al. 1978, Spitters and Aerts 1983, Cousens et al. 1987, Spitters 1984). The Nitrogen-Tillage-Residue Management (NTRM) model is a simulation model of the soil environment and its effect on crop growth (Shaffer et al. 1983, Shaffer and Larson 1987). Increased emphasis on sustainable and low-input agricultural systems indicated that an NTRM submodel to simulate the interactions of crop and weed components under environmentally stressed and unstressed conditions was needed. A crop-weed competition field study was undertaken to provide information for model development. The objective of this paper is to report the crop-weed interactions observed over two growing seasons.

METHODS

Field experiments were performed during the 1987 and 1988 growing seasons on a Nunn clay loam soil (fine, montmorillonitic, mesic Aridic Argiustoll) located at the Colorado State University South Farm in Fort Collins. Corn (*Zea mays* L. var. Pioneer 3906) was grown in monoculture and in mixture with redroot pigweed (*Amaranthus retroflexus* L.). A redroot pigweed monoculture was added in 1988. A randomized complete block design with a split plot arrangement was used. Three main treatments consisted of 1) irrigation with N-fertilization, 2) irrigation without N-fertilization. and 3) no irrigation with N-fertilization. Main treatments were split into sub-treatments consisting of corn populations of 86,000, 42,000, and 0 (1988 only) plants ha^{-1} grown with pigweed populations of 520,000, 260,000, and 0 plants ha^{-1} at each corn density. Plots measured 8.3 m by 6.7 m with three replications.

Irrigation water was applied before significant visible stress could be observed. Fertilized plots received 200 kg ha^{-1} of N in the form of ammonium nitrate in April, 1987 and as urea in October, 1987. Each spring, EPTC herbicide was applied at 4 kg ha^{-1} active ingredient as a preplant, soil incorporated treatment to obtain initial, low redroot pigweed populations. Seedbeds were prepared with spring moldboard plowing and disking in 1987 and by autumn moldboard plowing followed by spring disking in 1987—88. Corn was seeded on May 8, 1987 and April 29, 1988 with a 0.76 m row spacing. to obtain 86,000 plants ha^{-1} corn populations.

After emergence, appropriate plots were thinned to 43,000 plants ha^{-1} to obtain low corn populations. Redroot pigweed populations were seeded on the same dates as corn and emerged at about 520,000 plants ha^{-1} for high populations. This density was thinned to 260,000 plants ha^{-1} for medium redroot pigweed populations. Plots were sampled for corn and redroot pigweed above-ground dry matter and population density by harvesting 1 m of row. Samples were taken at mid season (first week of August) and harvest time (mid-October). Mean and standard deviations were calculated for dry matter and density data. In 1988, light interception was measured mid-season at full corn canopy using a light ceptometer bar[4] (Decagon Devices 1987). Readings were taken at 30-cm increments through the plant canopy, from ground level to the top of the dominant canopy. Interception of photosynthetically active radiation (PAR) was adjusted to account for reflection (Decagon Devices 1987). The relationship between fraction of light interception and height in the canopy was described for mixed and corn monoculture stands.

RESULTS AND DISCUSSION

An analysis of dry matter production illustrates how each species reacted to stress in a monoculture (corn or redroot pigweed) and in a crop-weed (mixed) stand. Mid-season and final harvest above-ground dry matter amounts produced in 1987 and 1988 are presented in Table 1. Dry matter means from mixed stands with medium and high redroot pigweed densities were pooled since there were no statistical differences between those population levels.

Corn and redroot pigweed dry matter in monoculture or in mixed stands decreased with water stress. In 1987, water deficits decreased corn dry matter at harvest by 39% in monocultures and 58% in mixtures with pigweed. Pigweed dry matter at harvest in 1987 was reduced by only 6% in non-irrigated mixtures (Table 1). In 1988, water deficits in the dryland treatments caused corn mortality in both the monoculture and mixture resulting in a 94—95% reduction in corn dry matter at harvest compared to irrigated plots. Corresponding pigweed reductions in 1988 were 30% in monoculture and 23% in mixture.

In both years, nitrogen stress reduced corn and redroot pigweed dry matter. For example, in mixed stands in 1987 and 1988, corn dry matter at harvest in nitrogen-stressed irrigated stands was reduced by 19% and 30%, respectively, compared to irrigated, fertilized plots (Table 1). Corn monocultures showed corresponding yield reductions of 14 and 7%. Nitrogen deficits significantly decreased redroot pigweed dry matter in mixed plots with medium/high redroot pigweed populations. In 1987 and 1988, redroot pigweed dry matter for irrigated, non-fertilized mixed plots was reduced by 45 and 73%, respectively, compared with irrigated, fertilized plots (Table 1). Redroot pigweed dry matter in weed monoculture and mixed plots showed a characteristic loss of total biomass between mid-season and final harvest. For example, weed monoculture biomass was reduced by 40 and 42% for the irrigated and non-irrigated treatments, respectively. This effect was probably caused by senescence and loss of leaves as the plants mature, and by the death of smaller plants due to shading.

The total maximum biomass produced by the fertilized, irrigated redroot pigweed monoculture was 7,170 kg ha^{-1} compared with 10,920 kg ha^{-1} for the corn monoculture that also was fertilized and irrigated. The corn biomass value (10,480 kg ha^{-1})

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[4] Use of a product name does not imply endorsement by the Agricultural Research Service.

Table 1. Mid-season and harvest biomass (kg ha^{-1}) contributed by corn and redroot pigweed in monoculture and mixed populations.

				1987				1988			
				Pigweed		Corn		Pigweed		Corn	
				kg/ha							
Treatment	Population	Season[1]		$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
1) Irrig/Fert.	Corn[2]	mono	Mid	0	0	3850	615	0	0	6900	1830
		[3]	Har	460a	220	15610	580	440a	260	10480	230
		mixed	Mid	3190	580	4160	440	5830	1870	4560	1540
		[4]	Har	2370	2030	10490	2270	2920	1160	7160	1470
	Pig-weed	mono	Mid	—	—	—	—	7130	1650	0	0
			Har	—	—	—	—	4290	870	0	0
2) Irrig/Non-Fert.	Corn	mono	Mid	0	0	4370	540	0	0	6930	670
			Har	430a	50	13420	2520	430a	60	9790	2300
		mixed	Mid	3230	200	3730	1260	2440	770	3830	1080
			Har	1310	580	8470	2270	790	250	5000	1080
3) Non-Irrig/Fert.	Corn	mono	Mid	0	0	3970	1230	0	0	930	630
			Har	380a	310	9510	2110	1540a	480	680	70
		mixed	Mid	3360	690	3120	720	2170	360	780	970
			Har	2530	670	4420	680	2260	640	380	160
	Pig-weed	mono	Mid	—	—	—	—	5170	1520	0	0
			Har	—	—	—	—	2980	470	0	0

[1] Mid is sampled at mid-season; Har is sampled at harvest.

[2] Corn population at 46,000 plant ha^{-1}.

[3] Corn with medium/high populations of pigweed, mean based on 6 reps.

[4] Pigweed monoculture at high levels only, mean based on 3 reps.

[a] Late season invasion of pigweed after corn tasseled.

is low because of corn root worm and hail damage in 1988. The 1987 value of 15,612 kg ha^{-1} total dry matter probably is more representative of irrigated, fertilized corn grown at a population density of 43,000 plants ha^{-1}.

The relative proportion of each species to total dry matter production (Table 2) illustrates the response of plant species to water stress in a corn monoculture and in a crop-weed mixture. In 1987 and 1988, redroot pigweed proportion increased with water stress while corn proportion decreased in mixed plots (Table 2). In 1987, redroot pigweed and corn contributed 18 and 82%, respectively, to the total dry matter in irrigated, fertilized mixed stands and 36 and 64%, respectively, to total dry matter in non-irrigated, fertilized mixed stands. In 1988 non-irrigated fertilized plots, redroot pigweed increased with corn mortality causing a proportional increase (Table 2). Redroot pigweed relative proportion decreased with nitrogen stress while corn increased in mixed plots (Table 3). In 1987, redroot pigweed and corn contributed 18 and 82%, respectively, to the total dry matter in irrigated, fertilized mixed stands and 13 and 87%, respectively, to total dry matter in irrigated, non-fertilized mixed stands. The same proportion shift with nitrogen stress was apparent at mid-season and final harvest in 1988.

Table 2. Relative percentages of mid-season and harvest biomass contributed by corn and redroot pigweed under irrigated and non-irrigated conditions.

			1987		1988	
			Pigweed	Corn	Pigweed	Corn
Treatment[1]	Population	Season[2]	------% of Total------			
Irrigated	Corn[3] mono	Mid	0.0	100.0	0.0	100.0
		Har	2.9[4]	97.1	4.0[4]	96.0
	mixed	Mid	43.4	56.6	56.1	43.9
		Har	18.4	81.6	28.9	71.1
Non-irrigated	Corn mono	Mid	0.0	100.0	0.0	100.0
		Har	3.8[4]	96.2	69.5[5]	30.5
	mixed	Mid	51.9	48.1	73.7	26.3
		Har	36.4	63.6	85.5	14.5

[1] *All treatments received fertilization.*

[2] *Mid is sampled at mid-season;har is sampled at harvest.*

[3] *Corn population at 43,000 plants ha*$^{-1}$.

[4] *Late season invasion of pigweed after corn tasseling*

[5] *High pigweed proportion due to corn mortality*

Fractional interception of PAR increased as depth in the canopy increased for both corn monoculture and mixed stands. There was little difference in canopy light interception between irrigated-fertilized and irrigated non-fertilized corn monocultures (Fig. 1 and 2). Light interception was significantly greater from 0 to 60 cm above the soil surface for mixed stands than for corn monocultures, regardless of treatment. Canopy light interception at 60—90 cm above the soil surface was greater in corn monocultures than in mixed stands among nitrogen stressed (Fig. 2) or water stressed plots (Fig. 3).

Table 3. Relative percentages of mid-season and harvest biomass contributed by corn and redroot pigweed under fertilized and non-fertilized conditions.

			1987		1988	
			Pigweed	Corn	Pigweed	Corn
Treatment[1]	Population	Season[2]	—————% of Total		—————	
Fertilized	Corn[3] mono	Mid	0.0	100.0	0.0	100.0
		Har	2.9[4]	97.1	4.0[4]	96.0
	mixed	Mid	43.4	56.6	56.1	43.9
		Har	18.4	81.6	28.9	71.1
Non-fertilized	Corn[3] mono	Mid	0.0	100.0	0.0	100.0
		Har	3.1[4]	96.9	4.2[4]	95.8
	mixed	Mid	46.4	53.6	38.9	61.1
		Har	13.4	86.6	13.6	86.4

[1] *All treatments received irrigation.*

[2] *Mid is sampled at mid-season;har is sampled at harvest.*

[3] *Corn population at 43,000 corn plants* ha^{-1}.

[4] *Late season invasion of pigweed after corn tasseling*

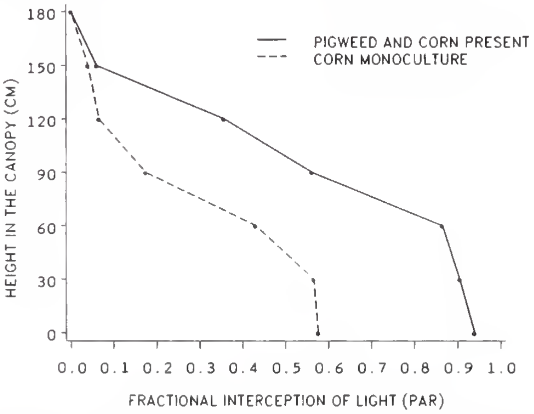

Figure 1. Fractional interception of light (PAR) in the plant canopy for redroot pigweed and corn grown under irrigated, fertilized conditions.

CONCLUSIONS

Corn dry matter production was more adversely affected by water stress than was redroot pigweed dry matter production, while nitrogen stress more adversely affected redroot pigweed dry matter production relative to corn. The relative percentage of total dry matter for corn and redroot pigweed shifted under stressed conditions. As water stress levels increased among fertilized mixed stands, the percentage of total dry matter shifted downward for corn and upward for redroot

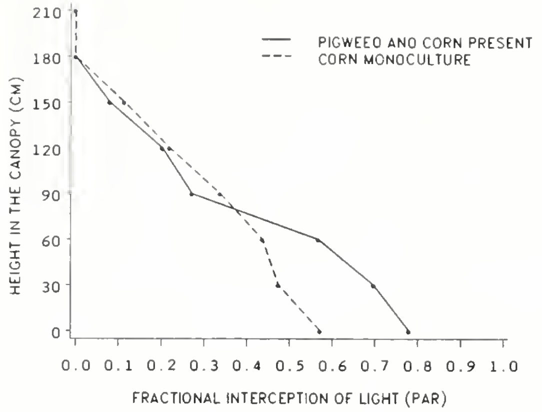

Figure 2. Fractional interception of light (PAR) in the plant canopy for redroot pigweed and corn grown under irrigated, non-fertilized conditions.

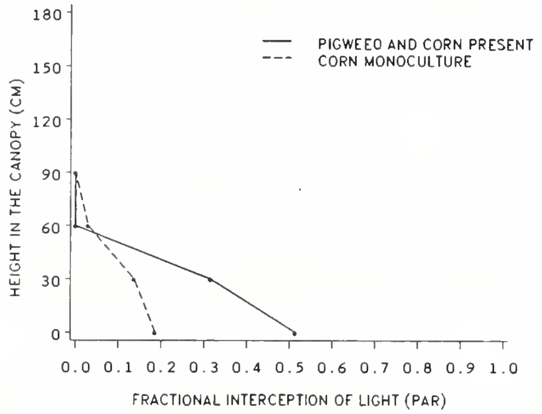

Figure 3. Fraction interception of light (PAR) in the plant canopy for redroot pigweed and corn grown under non-irrigated, fertilized conditions.

pigweed. Nitrogen stress among irrigated mixed stands caused the percentage of total dry matter to shift upward for corn and downward for redroot pigweed. Light interception was greatest throughout the canopy in mixed (corn and medium or high redroot pigweed) unstressed stands. Water and nitrogen stress conditions in corn monocultures produced canopies which intercepted more light higher in the canopy than mixed stands.

Crop and weed interactions are particularly interesting when low input agriculture becomes an objective. The changes in species proportion with nitrogen stress indicate properly managed nitrogen levels in the presence of irrigation may favor corn and control redroot pigweed dry matter production with minimal use of herbicides. Such crop-weed interactions must be considered for crop simulation models to be accurate in estimating crop responses to inputs. The information and data obtained from this study are currently being incorporated into a crop-weed interaction subprogram for the NTRM simulation model. This model will include competitive interactions for light, water, and nitrogen.

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Placement of N-Fertilizer for Conservation Tillage Winter Wheat in Livestock Grazing Systems in Southern Plains

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Rao, S.C. and T.H. Dao. 1991. Placement of N-fertilizer for conservation tillage winter wheat in livestock grazing systems in southern plains. Pages 149-156 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

ABSTRACT

Conventional management practices for annual cropping systems of winter wheat were reassessed under conservation tillage to identify practices which allow these production systems to attain their yield potential in the Southern Plains. Surface placement of nitrogen fertilizers were studied during 1985 to 1987 to determine the N-use efficiency of winter wheat (*Triticum aestivum* L.) under conventional and conservation tillage systems. Low harvest index (grain/total DM ratios) for no-tillage treatments indicated a high degree of cheat (*Bromus secalinus)* and downy brome (*B. tectorum)* competition, resulting in lower fertilizer N-use efficiency and grain yield when compared to plowed plots. Crop residues left on the surface provided a favorable environment for the establishment and proliferation of cheatgrasses, which competed for water and nutrients to reduce grain yield. Placement of N-fertilizer in a narrow band on the soil surface between wheat rows improved grain yield compared to broadcasting in both tillage systems only in 1985. Good control of cheatgrasses and banding of N-fertilizer on the soil surface may enhance the probability of success of sustainable conservation tillage production system in the Southern Plains.

INTRODUCTION

Acceptance of conservation crop production practices has increased in the last decade, mainly due to their capacity for soil and water conservation and reduction of energy inputs, compared to conventional production systems. However, increase in soil surface residue due to adoption of reduced tillage practices have led to reduced yield from increased weed competition. Reduction in tillage intensity and increased use of surface-applied fertilizers have intensified problems with weed grasses, particularly *Bromus* spp., in winter wheat because the mulch creates an ideal microenvironment for their establishment (Massee 1976, Thill et al. 1984, Dao 1987). Peeper (1984) summarized the progress in herbicide development for *Bromus* spp. control and concluded that metribuzin (4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one) is currently the only registered herbicide that is highly effective against *Bromus* spp. in small grains. However, post emergence activity of metribuzin, and the few wheat cultivars that are tolerant of the herbicide (Ghadiri et al. 1981 and Runyan et al. 1982), emphasize the need for new chemicals and control methods. Dao (1987) has reported improved selectivity and a wide range of cultivar tolerance to a new metribuzin analog (S-ethyl metribuzin) for control of cheat (*Bromus secalinus* L.) and downy brome (*B. tectorum* L.) in winter wheat.

Conservation and no-tillage systems conserve soil water for crop production more efficiently than conventional systems (Lonkerd and Dao 1985, and Unger and Wiese 1979). The maintenance of a surface residue mulch minimizes soil water evaporation while reducing soil erosion. However, the higher soil water contents and observed increases in soil microorganism in mulched soil surface (Broder et al. 1984) can lead to increased N losses via leaching and denitrification (McMahon and Thomas 1976). The microclimate of microbially-active surface soils under no-tillage also is more conducive to immobilization of applied N. Therefore, a no-tillage system may require more N-fertilizer to attain its production potential in the initial stage of adoption of the practice. Since N-fertilizer represents a sizable portion of the production cost, increased N losses temporarily may negate some of the advantages of no-tillage with respect to energy conservation and production costs. Fertilizer application practices commonly used with conventional tillage must be reassessed to improve N-use efficiency and crop yields for no-tillage production systems. The objectives in this study were to investigate the use of N placement to improve N-use efficiency in conservation tillage system for dryland continuous winter wheat that is dually used as a winter forage and as a grain crop in the Southern Great Plains.

MATERIALS AND METHODS

A series of field experiments were conducted to evaluate N rates and placement geometry in no-till (NT) and moldboard plowed (MB) plots at the Forage and Livestock Research Laboratory, USDA, ARS near El Reno, OK. The nitrogen placement study was established on Renfrow silt loam (fine, mixed, thermic Udertic Paleustolls) during 1985 1986 and 1987. After wheat harvest in June of each year, stubbles were left standing in the field until planting of the next wheat crop in October. Wheat cultivar 'TAM 101' was seeded at rate of 100 kg ha^{-1} with a 25 kg ha^{-1} starter fertilizer (18-46-0) to provide 4 kg N and 12 kg P ha^{-1}. In the spring, additional ammonium nitrate at rates of 50 and 100 kg N ha^{-1} were either surface broadcasted (BR) or placed on the surface in a narrow band (BN) between wheat rows. The experiment was established according to a split-plot design. Tillage treatments were the main plots replicated three times and N placement and rates were the sub-plots. All tillage and N treatments were fixed in space and repeated on the same plots for the duration of the study. At maturity, samples from two center rows (30-cm length) from each plot were hand harvested to determine yield and N concentration of grain and straw. Nitrogen efficiency parameters such as N-uptake, total above ground dry matter/N-uptake and nitrogen harvest index (ratio of grain N content to total above ground plant N) were calculated as suggested by Maranville et al. (1980).

Separate analysis of variance were computed for each year due to differences in years using SAS GLM procedure. Split-plot in time analysis was used with tillages as main plot, placement as sub-plot, and weeks as sub-sub plot with appropriate interactions. Weeks and weeks X tillage interactions were significant in most of the analysis but not placement of fertilizer. To assess the differences among placement geometry and tillage method, linear regression analyses were used to estimate and compare the rate of change over weeks for each trait within year (Snedecor and Cochran 1980).

RESULTS AND DISCUSSION

Precipitation received during growing seasons 1984-85 (83.4 cm) and 1986-87 (190 cm) were higher than the 10 year average (71.8 cm) while the 1985-86 precipitation was similar to it. Their distribution patterns also were different in each growing season (Table 1). Although the precipitation distribution is bimodal in all three years, the peak rainfall periods in the fall and spring were shifted by one or two months. Therefore, wheat growth and the fate of fertilizer were differentially affected by the timing of precipitation.

Table 1. Precipitation (cm) for the study period and 10-year average at El Reno, OK.

Month	1984-85	1985-86	1986-87	1977-87
September	0.4	15.0	25.5	6.9
October	5.3	8.1	16.8	8.6
November	4.2	3.9	7.9	4.3
December	14.6	0.3	1.6	2.9
January	2.4	0.0	4.9	2.8
February	8.3	0.7	7.0	3.5
March	15.0	1.1	4.9	6.2
April	12.8	7.5	0.1	6.3
May	2.1	20.3	28.3	17.8
June	18.0	13.1	11.6	12.2
Total	83.4	70.3	109.0	71.8

Overall. there was no significant effect of surface placement geometry of the fertilizer nitrogen on spring wheat forage accumulation in all three years (Fig. 1). N uptake. crude protein content, and N-use efficiency index in wheat foliage were not affected under either tillage management. The unexpected lack of N placement effect on vegetative growth and forage N uptake and assimilation was not explained. Placing the N-fertilizer as a point source would minimize N-use by weeds and immobilization in microbial biomass at or near the soil surface and the mulch layer because smaller portion of the soil would be in contact with the fertilizer. The effect should have been detected soon after fertilizer application. in moldboard plowed plots where good *Bromus* spp. control existed. At harvest, surface banding of fertilizer N increased grain yield only in 1985, as none of the N assimilation indices were significantly higher than those of the broadcast treatment (Table 2). The yield improvement may have resulted from an interaction of fertilizer banding with another factor which might, in 1985, be climatic conditions in the spring of that crop year.

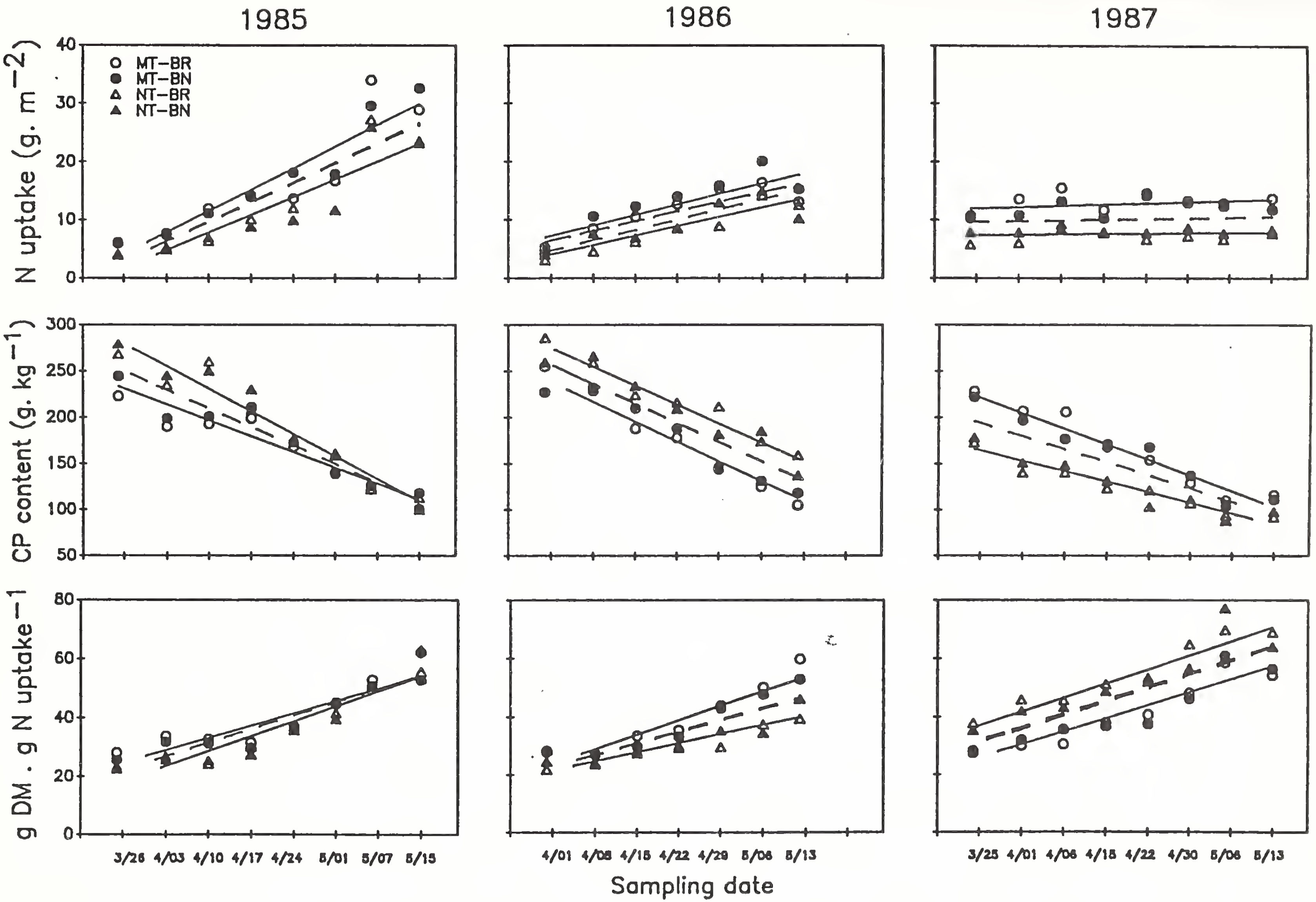

Figure 1. Effects of nitrogen placement (- - -) and tillage methods (———) on N-uptake, crude protein content of wheat forage, and N-use efficiency during 1985-87. (MT, moldboard tillage; NT, no-tillage; BR, broadcasting; and BN, surface banding).

The effect of tillage method on wheat growth and N-use were variable with year during 1985-87 (Fig. 1). There was no difference in the rate of N uptake was detected between tillage method in all 3 years, but the moldboard plowed wheat plant initially took up more N than wheat grown under no-tillage beginning at the time of foliage sampling in March of each year. As Dao and Nguyen (1989) have shown, the difference was due to the dissimilar stage of development and growth of wheat plant under two differing cultural methods on a common calendar date. Consequently, foliage crude protein contents of no-till wheat, being of a less mature plant, was higher than moldboard-plowed wheat in 1985 and 1986, but not in 1987.

However, the foliage N-use efficiency data indicated a consistently low efficiency in these no-till plots, compared to plowed plots. These data also revealed another confounding effect that clouded the tillage effect in this study (Fig. 1). There was severe competition for the nitrogen from cheat grasses with the crop in no-till plots in all three years, with the most deleterious effect on grain yield seen in 1986 and 1987 (Fig. 1 and Table 2). Grain yield in no-till during 1985 averaged 82 g m^{-2} higher compared to plowed plots. The percentage of grain N to total above ground plant N (NHI) in no-till was 14.4% higher compared to plowed plots. Lower grain yield and NHI in plowed plots during 1985 could be attributed to lower amount of precipitation received during late April and May of 1985, which may have affected the translocation of soluble compounds from vegetative parts of the plants to the grain. No-tillage has greater soil water conservation efficiency (Lonkerd and Dao 1985), and may have benefited from the greater moisture storage in increasing grain yield and NHI. In 1986 and 1987 grain yields were higher in plowed plots compared to no-till. Inadequate control of cheat and downy brome in these no-till plots increased weed competition as indicated by harvest indices (grain/total DM) i.e., 0.19 vs 0.26 and 0.21 vs 0.28 in 1986 and 1987, respectively, compared to plowed plots may have contributed to the lower grain yield. These results agreed with the work of Dao (1987) on the influence of crop residues on cheat and downy brome establishment and proliferation in no-till wheat.

These results suggested that competition of grass weeds, amount and distribution patterns of precipitation and the placement of fertilizer played an important role in determining N-use efficiency and grain yield under these two tillage systems. Crop residues have a deleterious effect on early growth and plant establishment, providing a niche for the establishment and proliferation of cheatgrasses, which compete for light, water and nutrients. The availability of selective herbicides for their control such as S-ethyl metribuzin is necessary to improve N-use efficiency of winter wheat. Nitrogen application geometry also must be adjusted in order for conservation tillage systems to attain their production potential. These improved practices would enhance the probability of success for a sustainable no-till production system in Southern Plains.

Table 2. Influence of tillage and N-placement on the yield and N-use efficiency in wheat during 1985-87.

		Tillage			N-Placement	
Trait	MB[1]	NT	LSD[2]	BR	BD	LSD[2]
		1985				
Straw yld. (g m^{-2})	568	521	NS	577	512	61
Grain yld. (g m^{-2})	227	309	76	259	277	13
Harvest Index	0.29	0.37	0.07	0.31	0.35	0.02
Straw CP (g kg^{-1})	77	62	NS	67	72	NS
Grain CP (g kg^{-1})	155	146	4	152	149	NS
N-uptake (g m^{-2})	12.7	12.3	NS	12.4	12.4	NS
NHI (%)	44.8	59.2	9	50.7	53.3	NS
		1986				
Straw yld. (g m^{-2})	739	640	NS	652	726	NS
Grain yld. (g m^{-2})	267	147	65	194	220	NS
Harvest Index	0.26	0.19	NS	0.23	0.23	NS
Straw CP (g kg^{-1})	73	87	13	75	85	NS
Grain CP (g kg^{-1})	158	158	NS	157	159	NS
N-uptake (g m^{-2})	15.4	12.8	NS	12.6	15.6	NS
NHI (%)	44.0	30.0	NS	38.0	36.0	NS
		1987				
Straw yld. (g m^{-2})	440	426	NS	411	455	NS
Grain yld. (g m^{-2})	176	116	NS	128	164	NS
Harvest Index	0.28	0.21	0.07	0.24	0.26	NS
Straw CP (g kg^{-1})	52	48	NS	51	49	NS
Grain CP (g kg^{-1})	168	157	7	159	166	6
N-uptake (g m^{-2})	8.3	6.2	NS	6.7	7.8	1
NHI (%)	56.4	46.8	NS	48.5	54.7	NS

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[1] *MB = Moldboard, NT = no-till, BR = broadcasting, BD = banding, NHI = Nitrogen harvest index.*

[2] *LSD at* $\alpha = 0.05$.

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Sustaining Livestock Production and Profit on Range: Managing for Risk

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INTRODUCTION

Range livestock production is a risky business. The producer must balance productivity, stability, and sustainability (Conway 1987). If a production system offers high average profits (high productivity) but a great deal of year-to-year variation in profits (low stability), or threatens the long-term productivity of the resource base (low sustainability), it may be less desirable than a system with somewhat lower productivity but high stability and sustainability. This is especially true of range systems in which 1) the profit margin is so low that the producer may not be able to survive more than one or two successive years of losses, and 2) the time and cost of restoring depleted range may be prohibitive.

Three major sources of risk must be considered in range livestock production.

- Variability of weather, especially precipitation, which is reflected in variability of forage production.
- Uncertainty about livestock prices.
- Danger of permanent damage to range plant communities and soils.

Several approaches to risk definition and management have been reported. Parsch and Loewer (1987) used the GRAZE model to quantify the variability in forage production expected from ten weather scenarios, and the mean and variance of net returns from cattle grazing under ten grazing systems in each scenario.

Torrell et al. (1989) examined data from Sims et al. (1976) and concluded that stocking rates which produce maximum short-term returns were unlikely to reduce sustainability of range grazing. Blake et al. (1984) and Nance et al. (1985) presented methods for predicting beef prices.

Antle (1987) and Binswanger and Barah (1980) noted that actual risk levels may differ considerably from risk levels as perceived by producers. McSweeny et al. (1987) discussed ways in which to present risk to producers.

This presentation will define risks caused by variability in weather and hence in forage production for the High Plains of Wyoming, and will develop a stocking strategy for maximizing returns in the face of such variability. Impacts on this strategy of price variability and the potential for damage to range plant communities will be discussed.

METHODS

Three types of information are needed for risk analysis:

1. Responses of livestock, range plant communities, and other segments of the range ecosystem to management.
2. Long-term data sets demonstrating variability of weather, prices, and if possible of the responses listed in item 1.
3. Simulation models to examine long-term impacts of management strategies.

The climate generator (Richardson et al. 1987) and the plant component (Hanson et al. 1988) of the SPUR model (Wight and Skiles 1987) were used to generate a 50-year sample of forage production on mixed-grass prairie rangeland as found on the High Plains of eastern Wyoming.

The optimum stocking rate (SR) for each year was calculated, using the method outlined by Hart et al. (1988). Briefly, this method assumes that average daily gain or $ADG = a - bH$, when H = stocking rate in steer-days ha^{-1} and a and b are constants for a particular type of range and cattle; b is adjusted for peak standing crop. Then gain ha^{-1} or $G = aH - bH^2$ and gross return ha^{-1} yr^{-1} or $R_G = P(aH - bH^2)$ when P = selling price per kg. If C = carrying cost animal^{-1} day^{-1} (including the margin between purchase price and selling price, interest, supplemental feed and veterinary costs. death loss, etc.), then net return to land, labor, and management or $R_{LLM} = PaH - PbH^2 - CH = (Pa - C)H - (Pb)H^2$. Maximum return ha^{-1} occurs when R_{LLM} no longer increases with an increase in H (stocking rate) or when $dR_{LLM}/dH = (Pa - C) - 2PbH = 0$, which is equivalent to $H = (Pa - C)/(2Pb)$. This value of H is the optimum SR or the SR at which return to land, labor and management is maximized.

Optimum SR was calculated for the predicted forage production of each of the 50 years at cattle prices prevailing in 1986 and 1987. Prices in 1986 (purchase price \$1.59, sale price \$1.37 kg^{-1}) were less than the average of recent years, while prices in 1987 (purchase price \$1.71, sale price \$1.59 kg^{-1}) were well above average. Carrying costs (C) were \$0.70 $head^{-1}$ day^{-1} in 1986 and \$0.71 in 1987. An initial steer weight of 250 kg and a 150-day grazing season were used.

Returns to land, labor and management were calculated at the optimum SR for each set of prices, at the optimum SR ± one-third, and at SR's of 40, 60 and 80 steer-days (SD) ha^{-1}. Means and distributions of net returns under each SR were determined.

Finally, forage production under average SR's of 47 and 63 steer- days ha^{-1} (the moderate and high SR's of Hart et al. 1988) was compared to production of ungrazed range to indicate whether production would be reduced at the SR's studied.

RESULTS AND DISCUSSION

Peak standing crop ranged from 570 to 1750 kg ha^{-1} of dry matter (Fig. 1). with a mean of 1170 and a standard deviation of the mean of 280 kg ha^{-1}. SPUR produced fewer years of near-average forage production and more years of forage production substantially above or below average than would be expected in a statistically normal distribution. Optimum SR's ranged from 24 to 72 SD ha^{-1} at 1986 prices and 31 to 94 SD ha^{-1} at 1987 prices; averages were 48 and 63 SD ha^{-1}, respectively.

The Soil Conservation Service recommends an initial SR of 36 SD ha^{-1} on mixed-grass prairie in good condition (SCS 1986). At fixed SR's of 40, 60 and 80 SD ha^{-1}, net returns to land, labor and management ranged from \$4.97 to \$22.96, -\$12.61 to \$27.86, and -\$43.57 to \$28.37, respectively, at 1986 prices (Fig. 2). At 1987 prices, comparable figures were \$16.53 to \$37.41, \$1.50 to \$48.47, and -\$29.05 to \$54.45. As fixed SR's increased, the probability of higher returns in years of high forage production also increased, but so did the probability of greater losses in years of low forage production. At 80 SD ha^{-1}, losses occurred in 26% of the years at 1986 prices and 8% of the years at 1987 prices.

When SR was adjusted annually to the optimum for current forage production and prices, returns ranged from \$9.41 to \$28.70 at 1986 prices and \$18.23 to \$55.61 at 1987 prices. At 1986 prices, the average net returns at 40, 60, 80 and optimum SD ha^{-1} were \$17.63, \$15.86, \$7.04, and \$19.19 ha^{-1}. The pattern was similar at 1987 prices, although net returns were higher. Returns at 40, 60, 80 and optimum SD ha^{-1} were \$31.22, \$34.55, \$29.70, and \$37.19 ha^{-1}.

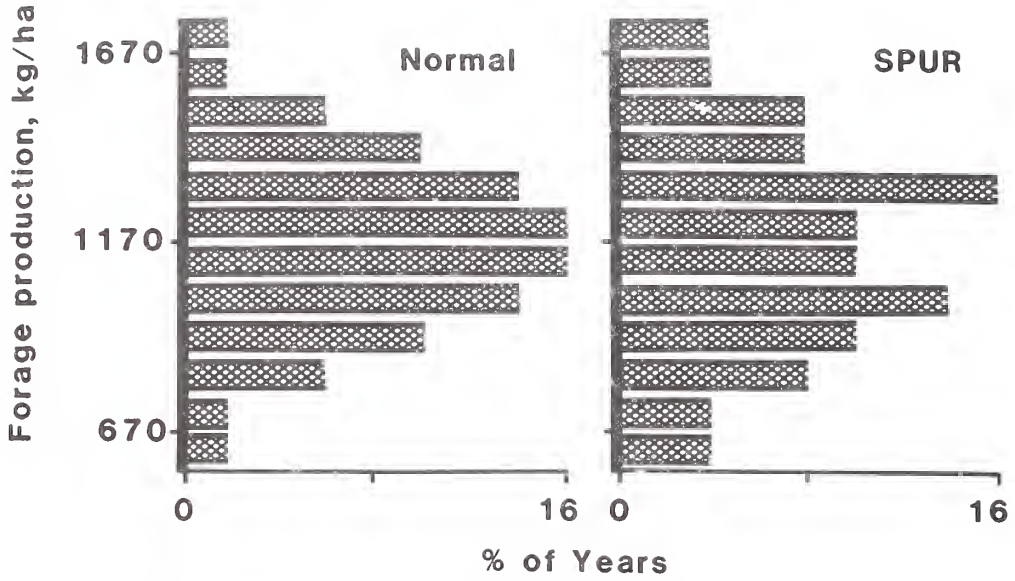

Figure 1. Frequency distribution of levels of forage production generated by SPUR, compared to statistically normal distribution.

To take advantage of flexible optimum SR's, it is necessary to estimate SR early in the season. This can be done with some accuracy on the High Plains, where forage production is largely determined by precipitation in March, April and May, before and in the early days of the grazing season (Hart 1987). Estimation may be less accurate in other regions, but over- or under-estimating the optimum SR by one-third reduced average net returns only from \$19.19 to \$16.95 at 1986 prices and from \$37.19 to \$32.84 at 1987 prices (Fig. 2). These levels of return are nearly the same as those at 60 SD ha^{-1}, but with the reduced variation noted at optimum SR. Risk from over- or under-estimating optimum SR seems to be minor.

Risks from over- or under-estimating prices when setting optimum SR's may be even smaller. If SR is set at optimum for 1986 prices when actual prices are at 1987 levels or vice versa, average returns will be reduced only about 1%. Greater discrepancies between expected and encountered prices will produce greater reductions, but this risk is less than that from improper SR. The greatest risk posed by uncertain prices is that of underestimating the margin, usually negative, between buying and selling price of cattle. That risk is beyond the scope of this presentation.

The risk posture of the individual cattle producer also must be considered. A risk-averse producer may worry that forage production or selling price has been overestimated, and will therefore choose a stocking rate less than the calculated optimum. On the other hand, a producer in a sound financial position and willing to take more risk may stock at higher than the calculated optimum. The latter strategy increases the risk of potential damage to range condition and production.

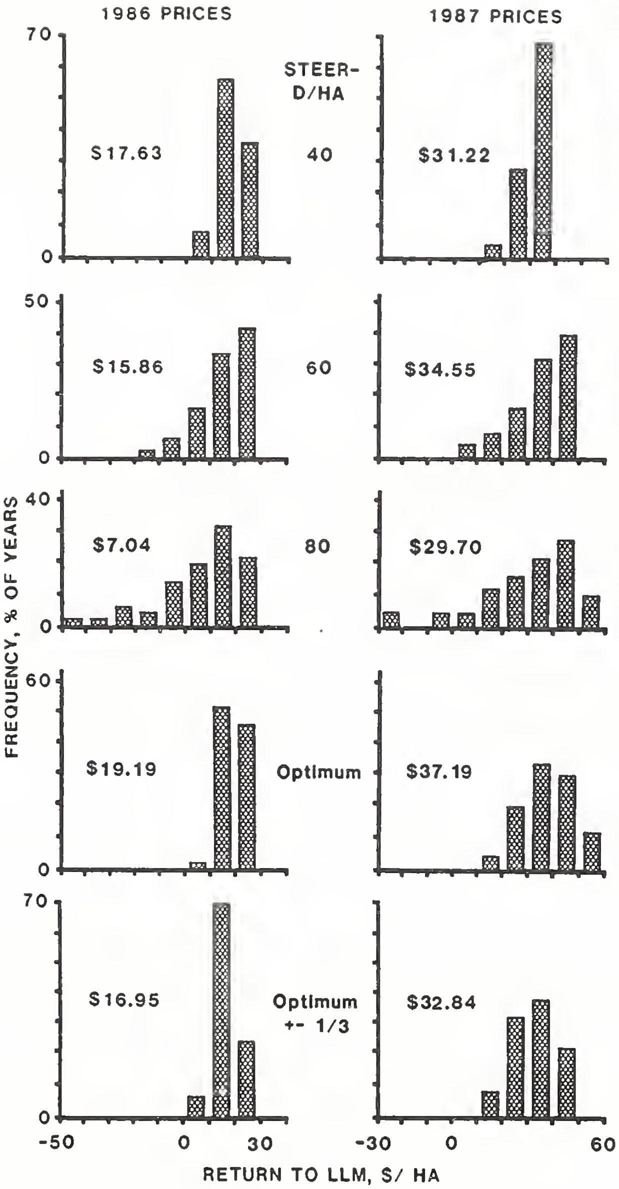

Figure 2. Frequency distribution of net returns to land, labor and management under fixed stocking rates (SR) of 40, 60, and 80 steer-days (SD)/ha, flexible optimum SR, and optimum SR ± 1/3 at 1986 and 1987 cattle prices.

No reduction in range condition (Hart et al. 1988) or forage production (Fig. 3) has been observed after seven years of grazing on High Plains mixed-grass prairie. In the first two years of this study, production of the moderate- and heavy-stocked pastures (47 and 63 SD ha^{-1}, respectively) averaged 81% of production on an adjacent area, ungrazed for 40 years. In the sixth and seventh year of the study, production under grazing was 87% of that on the ungrazed area, with no difference between 47 and 63 SD ha^{-1}.

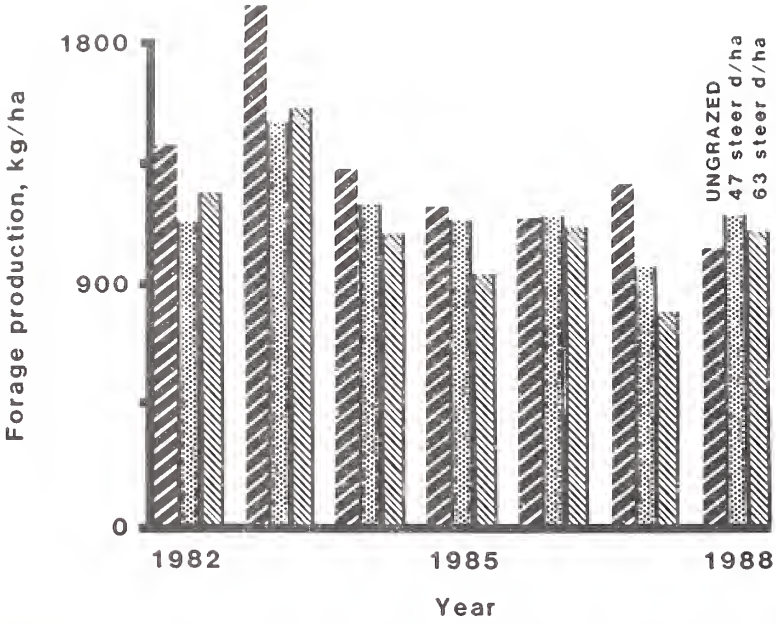

Figure 3. Range forage production under moderate and heavy grazing (47 and 63 steer-days/ha, respectively) versus forage production of ungrazed range.

CONCLUSIONS

Profits on a mixed-grass prairie grazed at a fixed moderate SR will be higher than on similar prairie grazed at a fixed low or high SR. Variation in profits (risk) will be somewhat more than at a fixed low SR but much less than at a fixed high SR. A flexible optimum SR will increase profits and decrease risk even further. Small errors in estimating optimum SR, because of uncertainty about forage production or cattle prices, present little risk. Optimum SR's present little risk of permanent damage to range condition or forage production.

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Specialty Crops in Sustainable Systems

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Croissant, R.L. and D.L. Johnson, 1991. Specialty crops in sustainable systems. Pages 165-170 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

INTRODUCTION

The recent rise to national prominence of new food and industrial crops such as kenaf (*Hibiscus cannabinus* L.), sunflower (*Helianthus annuus* L.), canola (*Brassica napus* L.), guayule (*Parthenium argentatum* A. Gray), and jojoba (*Simmondsia chenensis* (Link) Schneider), has spurred interest in the development of alternative and specialty crops for the High Plains. These new crops do not have large commercial markets when compared to wheat (*Triticum aestivum* L.) or corn (*Zea mays* L.), but they may add to the regional diversity and sustainability of High Plains cropping systems. Common characteristics required of specialty crops for sustainable systems are:

1. Drought tolerance.
2. Resistance to insects and diseases.
3. Suitability to a wide-range of soil types and soil fertility levels.
4. High economic value.

The first objective of this study was to evaluate grower response to selected specialty crops in Colorado. Crops selected for evaluation were:

Adzuki bean (*Vigna angularis* (Willd.) Ohwi and Ohashi)
Amaranth (*Amaranth cruentus* L. and *A. hypochondiacus* L.)
Black bean (*Phaseolus vulgaris* L.)
Blue corn (*Zea mays* L.)
Canola (*Brassica napus* L.)
Edible soybean (*Glycine max* (L.) Merr.)
Mungbean (*Vigna radiata* L.)
Pearl millet (*Pennisetum americanum* (L.) Leeke)

The crops selected meet the four criteria listed above and were acceptable by the growers cooperating with this study. A second objective was to assist growers in locating processing facilities and markets for their new crops because conventional marketing has not been developed in the area.

CROP CHARACTERISTICS

Prior to initiation of this study, some information was known about alternate crop production in Colorado, but the information was limited to a few studies conducted at Colorado State University Research Centers and private farms.

Pearl millet shows potential for growth in the High Plains due to its drought tolerance. An open-pollinated experimental pearl millet, 'SD01', was evaluated at Akron from 1983-86 and at Walsh from 1985-88. Yields ranged from 437 to 2433 kg ha^{-1}. Thereafter, an open-pollinated select pearl millet population was used in field studies where the selection criteria was based on dwarf plant height and plant height uniformity. By 1987, the selection was considered sufficiently uniform for field scale evaluation. In addition to the dwarf selection, row spacing and plant density studies provided the basis for field evaluations. Pearl millet markets were not in place during 1988 and marketing research is not expected to be conducted after 1990. Pearl millet grain yields have been 30-50% below grain sorghum (*Sorghum bicolor* (L.) Moench) yields. except in drought conditions. Under very droughty conditions, pearl millet grain yields have exceeded grain sorghum yields by 100%.

Canola, a type of rapeseed, is a high quality oilseed being grown on increased acres in the United States. Canola is used to make high quality cooking oil which is low in saturated and high in mono- and poly-unsaturated fats. Once established, canola has excellent drought tolerance in on-farm trials. Twenty winter and two spring canola populations were evaluated at Ft. Collins during 1986 to 1988. Winter entries were evaluated at Walsh from 1984 to 1988. Spring canola entries were evaluated at Del Norte from 1985 to 1988. Initial market testing for canola has emphasized high quality oil, but producers also have explored additional markets such as salad condiments and a substitute for poppy seed in baking. The spring cultivar 'Westar' was field evaluated at Del Norte in 1988. Field production of 'Westar' has averaged 2688 kg ha^{-1} over the past three years with 28 cm of supplemental irrigation and rainfall during the growth period. Winter cultivars have yielded 347 kg ha^{-1} to 3418 kg ha^{-1} in dryland trials at Ft. Collins, Colorado. In Colorado, some canola is being utilized for condiments since oil processing facilities are too distant to be economically feasible.

Mungbean germplasm was received from the National Seed Storage Laboratory for preliminary evaluation in 1986. Six hundred entries were evaluated for maturity and yield in a non-replicated trial in 1986 at Fort Collins. Lines selected in 1986 were planted at Mead and Walsh for evaluation and increase in 1987. Certified Berkin mungbean seed was used in on farm-trials in 1988 because of seed increase failures caused by hail the previous year. Berkin yielded 898 and 1373 kg ha^{-1} under commercial and research conditions respectively. This yield difference is probably a measure of the different harvest procedures because more shatter occurred in commercial harvest methods using a combine.

Amaranth trials were initiated in 1982 through 1984 at Fort Collins utilizing germplasm provided by the Rodale Research Center (Kutztown, PA) and the University of California, Davis. Production methods and information were provided by Weber et al. (1989). Selected lines from the American Amaranth Institute, Colorado State University, and The Rodale Research Institute were evaluated from 1985 to 1988 at Ft. Collins, Mead, Walsh, and Rocky Ford. Yields under dryland conditions at Fort Collins and Mead averaged 1511 kg ha^{-1} while trials at Rocky Ford yielded 1476 kg ha^{-1} under full irrigation. The 1988 trials at Walsh were lost because of severe soil crusting during seedling emergence.

Blue corn seed was purchased from the Talavaya Center in Espanola, NM. The cultivar (landrace) selected was identified as 'Hopi Blue' corn—a type defined as having superior quality for dryland production. Because of limited previous production experience by farmers, production field testing throughout Colorado was not initiated until 1988. On-farm yields of organically grown blue corn 'Hopi Blue' yielded 2172 kg ha^{-1} in 1988. Farmers growing blue corn with conventional production practices obtained yields of 2329 kg ha^{-1} in 1989.

Several types of beans offer promise as an alternate crop. Black bean production has been limited in Colorado. The increase in black bean consumption by southwestern ethnic groups and associated restaurants has offered expansion opportunities in the domestic marketplace. There appears to be additional markets for black beans in Central and South America. On-farm trials of black beans at Olathe yielded 1624 kg ha^{-1} in 1988 using full irrigation. Adzuki beans (called "red diamonds" in Japan because of their value) are an alternative to many legumes because of its forage potential and high seed value. In 1988, adzuki bean trials failed at Pueblo and Olathe using 'Arrowhead 1' (a selection provided by Arrowhead Mills, Hereford, TX) but yielded 550 kg ha^{-1} with irrigation at Rocky Ford in 1988. Dryland trials at Fort Collins yielded 827 kg ha^{-1} in 1987. Adzuki beans are better adapted to the cooler northern High Plains regions of Colorado than the warmer areas to the south. Edible dry soybean has received attention, especially in non-typical soybean areas such as the Grand Valley at Fruita. Production of premium quality edible soybean cultivars 'Prize' and 'Vinton' averaged 1239 kg ha^{-1} in organically grown farm trials and 2016 kg ha^{-1} in similar irrigated conventional evaluations in 1988.

ON FARM TRIALS

Research involving the feasibility of growing and marketing new crops was conducted by Colorado State University's new crops project to obtain preliminary information on grower success when producing and marketing new crops. Crops which appeared to be economically feasible were given priority in this project. Growers, identified by county extension personnel, were provided with a list of proposed crops for their area. Extension and research personnel determined which crops to consider in the study. Selection of crops was based on environmental factors including temperature, rainfall and elevation. Each interested grower received general information about the crops, assurances of production information updates, and assistance with marketing by Colorado State University research and extension personnel and the Colorado Department of Agriculture, Marketing Division.

Seed increases of material obtained from Talavaya, Espanola, NM, a nonprofit seed preservation group, were used when seed was not available from commercial companies. The seed lots obtained from Talavaya lacked the typical uniformity of conventional crops, but were suitable for the initial trials.

Extension personnel in the selected counties made direct contact with prospective growers. Research and Extension Specialists at Colorado State University requested that growers selected be community leaders and innovators. Extension personnel agreed to assist by coordinating information transfer between growers and the authors. Extension personnel also agreed to assist growers in record keeping of production costs and net returns. Extension specialists provided seed to growers at planting time. The number of participants and crops varied from county to county within Colorado (Table 1).

On-farm trials were established in 1988 with the financial assistance of the USDA Agricultural Marketing Service and the Federal-State Marketing Improvement Program. The growers selected crops for their farm as shown in Table 1. Production procedures were provided via extension publications. Growers were informed of markets if produce was grown under "organic" or conventional systems. Extension personnel were asked to act as a local source of information to provide quick evaluation and support during the project. Growers accepted into the program contracted with the Colorado Department of Agriculture (CDA) and agreed to provide detailed records of production procedures, costs incurred and marketing procedures. In exchange, the CDA guaranteed to reimburse production costs which ranged from $200.00 to $750.00 per acre depending on the crop. CDA provided each grower with a listing of local and national buyers and their standard requirements.

SUMMARY

The "New Crop" grower acceptability study had mixed success. Producers of blue corn, dry edible soybean, mung bean, canola, pearl millet, black bean and amaranth reported general satisfaction with the crops and most are willing to continue with these crops. All growers agreed that it requires at least two years to become efficient producers. Most expressed concerns with the associated costs of "organic" production which may be a major limitation to adaptation of some crops. Organic production is not required but most buyers pay premiums for the organic product. Half of the organic producers stated that they probably would not continue to use that method unless better technology could be provided, primarily on weed control.

Table 1. Participants and crops in the Colorado study, 1988.

County[1]	Crop	Status	Production[2]
Baca	Pearl Millet	Dryland	Conventional
E. Langin	Blue Corn	Dryland	Conventional
	Adzuki Bean	Irrigated	Conventional
	Edible Soybean	Irrigated	Conventional
	Mungbean	Irrigated	Conventional
	Amaranth	Irrigated	Conventional
Boulder	Blue Corn	Irrigated	Organic
L. Benner	Black Bean	Irrigated	Organic
	Mungbean	Irrigated	Organic
Mesa	Black Bean	Irrigated	Organic
T. Doherty	Mungbean	Irrigated	Conventional
	Edible Soybean	Irrigated	Conventional
	Adzuki Bean	Irrigated	Conventional
Otero	Amaranth	Irrigated	Conventional
E. Langin	Adzuki Bean	Irrigated	Conventional
	Edible Soybean	Irrigated	Conventional
	Mungbean	Irrigated	Conventional
Pueblo	Blue Corn	Irrigated	Organic
J. McClave	Adzuki Bean	Irrigated	Organic
	Mungbean	Irrigated	Organic
	Edible Soybean	Irrigated	Organic
Rio Grande *M. Dillon*	Canola	Irrigated	Organic

[1] *Includes Extension Agents cooperating with study.*
[2] *Organic production is free of synthetic pesticides and fertilizer during 1988 only.*

Table 2. Summary of Alternate Crop Yields and Remarks in the Colorado Study, 1988.

Crop	Sites	Yield Range	Comments
Adzuki Bean	4	0 - 550 kg ha^{-1}	Heat Stressed[1]
Amaranth	2	0 - 1477 kg ha^{-1}	Well Adapted[2]
Blue Corn	3	1086 - 2509 kg ha^{-1}	Very weak stalks
Black Bean	2	717 - 3024 kg ha^{-1}	Well Adapted
Canola	1	2688 kg ha^{-1}	Well Adapted
Edible Soybean	4	1046 - 2236 kg ha^{-1}	Well Adapted
Mungbean	5	1008 - 1337 kg ha^{-1}	Well Adapted[2]
Pearl Millet	1	0 kg ha^{-1}	Hail Storm

[1] *Adzuki beans sensitive to high temperatures.*

[2] *Sites lost from hail or wind.*

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Influence of Nitrogen Fertility on Water Use, Water Stress, and Yield of Winter Wheat in the Central Great Plains

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Nielsen, D.C. and A.D. Halvorson. 1991. Influence of nitrogen fertility on water use, water stress, and yield of winter wheat in the Central Great Plains. Pages 171-178 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

ABSTRACT

Available water supply and nitrogen fertility are the primary factors limiting dryland winter wheat (*Triticum aestivum* L.) yields in the Central Great Plains. The objective of this field study was to determine how level of nitrogen fertility influences water use, water stress, and yield of winter wheat grown under dryland conditions in the Central Great Plains. The study was conducted during the 1988 growing season on a Platner loam (fine montmorillonitic mesic Aridic Paleustoll) near Akron, Colordao. Nitrogen fertilizer was broadcast as NH_4NO_3 at 0. 28. 56, 84, and 112 kg N ha^{-1}. Canopy temperatures were measured with an infrared thermometer and used to compute the Crop Water Stress Index (CWSI). Evapotranspiration was computed and rooting depth inferred from weekly neutron probe readings of soil water content. Plant height, phytomass, rooting depth, water use, and grain yield increased with increasing N. CWSI was higher in the low N plots through flowering and early grain fill, primarily due to radiative and convective

transfer of heat from the warmer soil surface resulting from less vegetative cover, but also due to lower availability of soil water due to decreased rooting depth. During the dough stage, the lower water demand of the smaller, less vegetative plants from the 0 N treatment resulted in a lower CWSI than observed in the larger plants from the higher N treatments. Grain yield increased with increasing N up through the 84 kg ha^{-1} rate and was linearly correlated with cumulative evapotranspiration.

INTRODUCTION

Available water supply and nitrogen fertility are the primary factors limiting winter wheat yields in the Central Great Plains. These two factors are related in that increased N fertility can stimulate deeper rooting by winter wheat (Brown 1971) making a greater quantity of stored soil water available to the plant, thereby reducing potential water stress. However, a larger phytomass stimulated by increased N availability results in greater transpiration requirements. Thus, if sufficient soil water reserves are not available, greater water stress in high N treatments would also occur. Onken et al. (1989) found that water use efficiency based on final grain yield and cumulative growing season evapotranspiration increased significantly with increased N fertility for winter wheat grown in the Central Great Plains. Heading, flowering, and grainfilling are the most critical growth stages in winter wheat with respect to water requirement (Musick (1963), Singh (1981), Kirkham and Kanemasu (1983)). Musick and Dusek (1980) found that water stress during vegetative growth stages limits leaf and tiller development of winter wheat, while water stress during jointing increases rate of senescence and decreases number of spikelets per head. The objective of this study was to determine how level of nitrogen fertility influences water use, water stress, growth, and yield of winter wheat grown under dryland conditions in the Central Great Plains.

MATERIALS AND METHODS

Winter wheat (*Triticum aestivum* L., var. 'TAM 107') was planted in a Platner loam (fine montmorillonitic mesic Aridic Paleustoll) on 14 September 1987 at a rate of 68 kg ha^{-1} at the Central Great Plains Research Station (40″ 9' N, 103″ 9' W, 1384 m above m.s.l), 6.4 km east of Akron, CO. Row direction was north-south. The experimental area had been fallowed the previous 11 months following a corn crop. The experimental design was a randomized complete block of five nitrogen fertilizer treatments (0, 28, 56, 84, 112 kg N ha^{-1} broadcast as NH_4NO_3 just prior to planting) replicated four times. Individual plots were 9.1 by 12.2 m.

Soil water was measured weekly at one location in each plot from 21 April 1988 until grain harvest with a neutron probe (Model 3321, Troxler Electronic Lab., Research Triangle Park, NC)[5] at depths of 0.15, 0.46, 0.76, 1.06, 1.37, and 1.68 m. The data were used to calculate evapotranspiration by the water balance method (Rosenberg et al. 1983), and to infer rooting depth from changes in soil water

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[5] Trade names are included in the text as convenience to the reader and do not constitute any preferential endorsement by USDA-ARS of these products over other similar products.

content by depth between measurement times following the method of Bauer et al. (1989). Runoff and deep percolation were assumed to be negligible. The neutron probe was calibrated at the beginning of the season against gravimetric soil water data collected at the time of access tube installation. Crop height and growth stage were also measured weekly. Total phytomass was measured at heading and maturity. Final grain yield was sampled on 7 July 1988 from two 29.7 m^2 areas in the center of each plot.

Soil temperature was measured at 51 mm below the soil surface in one replication of the 0, 56, and the 112 N treatments with five copper-constantan thermocouples wired in parallel. The data were logged with a battery-powered data logger (CR21X, Campbell Scientific, Logan, UT) at 1-minute intervals and weekly averages were computed.

Canopy temperatures were measured with a hand-held infrared thermometer (IRT) with a field of view of 3° and an 8- to 14-micron waveband (Model 112 Agritherm, Everest Interscience, Fullerton, CA). Measurements were made two to three times a week between 1300 and 1400 MDT when the sun was unobscured by clouds. Data were recorded with a portable data logger (Polycorder, Model 516B, Omnidata International, Logan, UT). The IRT was calibrated before and after each daily measurement period using a blackbody reference. The IRT was hand-held at approximately 1.5 m above the soil surface. Six instantaneous measurements were made from both the SE and SW corners of each plot to insure that no soil surface was viewed. Air temperature and vapor pressure deficit were measured at a height of 1.5 m before and after each measurement period with an Assman-type psychrometer (Model 5230, WeatherMeasure, Sacramento, CA) in an open area adjacent to the plots. The twelve canopy temperature measurements per plot were averaged and used with the average air temperature and vapor pressure deficit to calculate one Crop Water Stress Index value (CWSI) per plot. CWSI was calculated following the method given by Idso et al. (1981) with the baseline equations for winter wheat given by Idso (1982).

RESULTS AND DISCUSSION

Large reductions in CWSI occurred in response to large precipitation events prior to jointing and heading (Fig. 1). Small precipitation events during heading and flowering maintained CWSI at less than 0.3. CWSI increased from 0.3 to 0.7 through late grainfilling due to low precipitation.

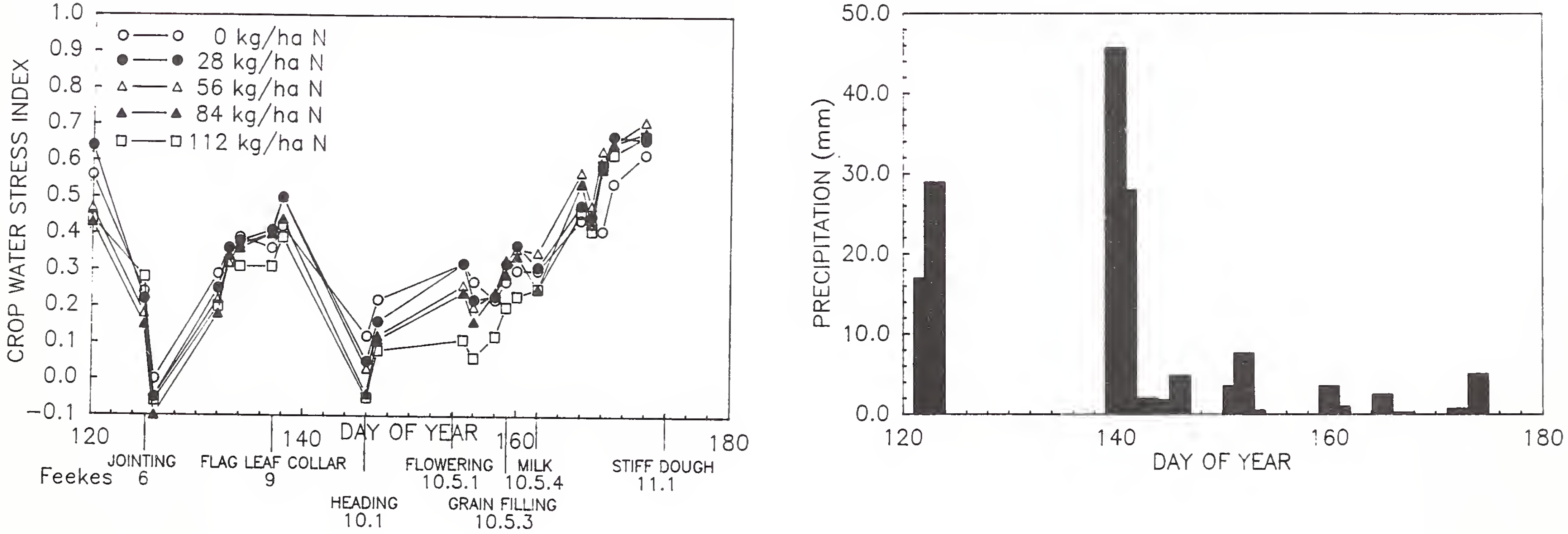

Figure 1. Crop Water Stress Index of winter wheat in 1988 as influenced by five N fertilizer treatments, and 1988 growing season precipitation.

Higher N rates tended to reduce the measured CWSI value, with the effects changing with growth stage (Fig. 2). From jointing through beginning grain fill, the low N treatments showed higher levels of water stress than the high N treatments. This can be explained by several factors. Throughout the growing season the low N treatments resulted in smaller plants with less leaf area. as noted in visual observations of the plots, and in the measurements of plant height and total phytomass (Table 1). This resulted in more of the incoming solar radiation penetrating to the soil surface. Morgan (1988) similarly noted increased leaf area and phytomass development in spring wheat due to a 100 kg ha^{-1} N application which resulted in approximately 30% greater interception of incoming photosynthetically active radiation (PAR).

Table 1. Effect of nitrogen fertility on depth of lowest root penetration (estimated by depth of water extraction), plant height, total phytomass, grain yield. test weight, heads ha^{-1}, and cumulative evapotranspiration (CET) of winter wheat.

			Phytomass		Grain			
N-Treatment kg ha^{-1}	Root Depth m	Plant Height m	At Harvest kg ha^{-1}	At Heading kg ha^{-1}	Grain Yield[1] kg ha^{-1}	Test Weight kg m^{-3}	Heads[1] acre^{-1}	CET mm
0	1.14	0.51	5376	6403	1824	724.6	2.11	285
28	1.22	0.52	6988	8072	2134	704.0	2.36	299
56	1.52	0.54	8084	9449	2692	687.3	2.86	328
84	1.52	0.56	9560	10307	2833	673.1	3.16	327
112	1.45	0.55	8303	9046	2397	675.7	2.84	329
LSD[3]	0.36	0.06	2152	2149	873	15.6	0.60	44

[1] *Grain yield was at 12% moisture.*

[2] *Million heads per acre.*

[3] *Differences between values within a column greater than the reported LSD are significantly different at $\alpha = 0.05$.*

In the present study this increased interception of PAR significantly decreased soil temperatures (Fig. 3). This increased thermal energy in the low N treatments was transferred convectively and radiatively to the overlying canopy. Using non-water-stressed baselines for partial canopies as suggested by Hatfield et al. (1985) instead of the non-water-stressed baseline for full canopies used in this study might have eliminated these differences. However, the lower CWSI values in the higher N treatments could in part be due to the greater rooting depth and greater available water supply to these plants (Table 1).

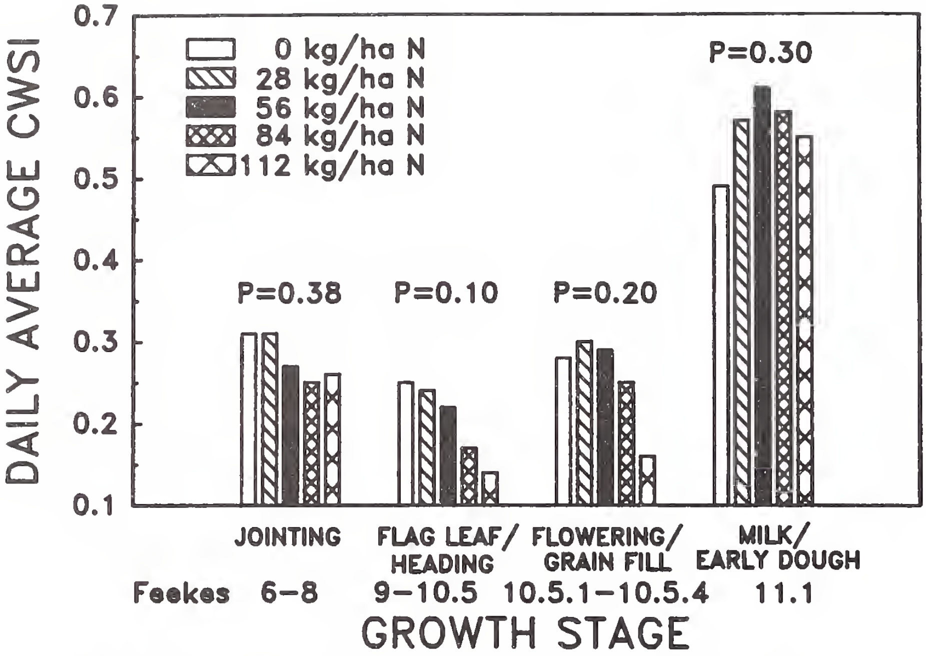

Figure 2. Daily average Crop Water Stress Index (CWSI) of winter wheat as influenced by five N fertilizer treatments. (P=probability for rejecting the null hypothesis).

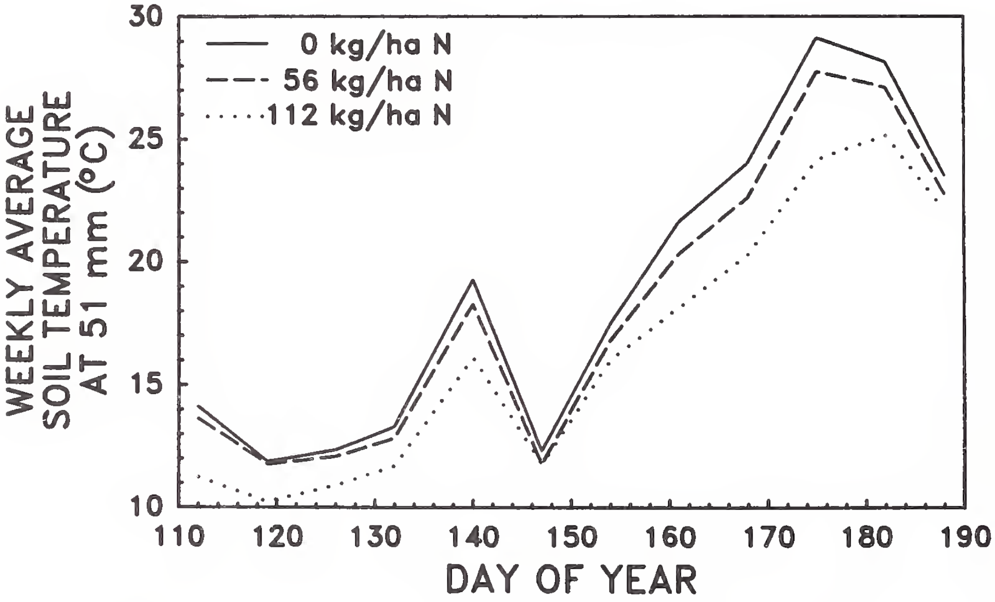

Figure 3. Weekly average soil temperature at 51 mm under a winter wheat canopy as influenced by three N fertilizer treatments.

During the dough stage of development, the 0 N treatment showed lower CWSI levels than the higher N treatments, even though soil temperature in this treatment was still higher than the other treatments. These smaller plants probably had a lower demand for water than the larger plants in the high N treatments. The extra available water from the increased rooting depth of the high N treatments was gone by this time resulting in plants under increased water stress. The higher test weights in the 0 N treatment could in part be a consequence of this lower level of water stress during the late grainfilling stage.

Grain yield increased with increasing N up through the 84 kg ha^{-1} rate (Table 1). Grain yield was linearly correlated with cumulative evapotranspiration (Fig. 4). This relationship is similar to one reported by Halvorson and Kresge (1982) for winter wheat growing in the Northern Great Plains. The slightly greater negative offset found in the current study is consistent with the somewhat higher evaporative demand in the Central Great Plains.

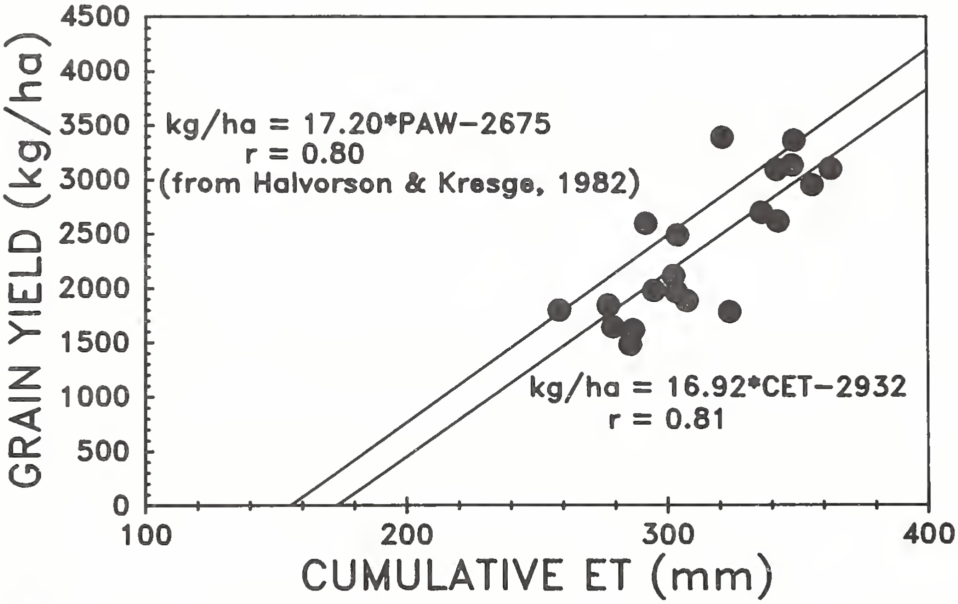

Figure 4. Relationship between cumulative growing season evapotranspiration (CET) and winter wheat grain yield. (PAW = Plant Available Water, mm).

SUMMARY AND CONCLUSIONS

Increased levels of N fertility stimulate both phytomass and root growth. The increased phytomass intercepts more incoming PAR, conferring a higher water requirement on the plant system while at the same time making more soil water available through the deeper root system. This gives the potential for greater yields when adequate or moderately limited water is available. But under conditions of severe water stress during the latter part of the growing season, the larger plant developed during the vegetative growth period may experience increased levels of water stress resulting in lower yields than plants fertilized at a lower N level.

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Winter Wheat Emergence Reduction Following Simulated Rainfall

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Hinkle, S.E. 1991. Winter wheat emergence reduction following simulated rainfall. Pages 179-186 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

ABSTRACT

Rain occurring within a few days of winter wheat (*Triticum aestivum* L.) planting with a furrow drill can significantly reduce plant emergence. A 30-minute, 5-year frequency storm of 30 mm reduced emergence more than 50% for wheat planted with V-shaped press wheels or in loose, clean-tilled soil conditions. Reduced tillage or increased surface residue along with the use of 75-mm wide, flat press wheels increased emergence significantly. Wheat planted in heavy residue and no-till soil conditions had full emergence with 0 to 40 mm water application in 30 minutes. An equation was developed to predict plant emergence levels after a heavy rain.

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is a major crop in the Central Great Plains region of the United States. It is primarily grown using two-year, wheat-fallow, clean-till management that leaves very little or no crop residue on the soil surface at planting time. Farmers will commonly till the soil four to eight times using sweep plows, rod weeders, one-way disks, tandem disks or field cultivators to control weeds during the fallow season. As a result of these tillage operations, the surface soil becomes a dry mulch which helps reduce soil water evaporation.

Winter wheat is planted primarily with grain drills that have disk or hoe-shoe openers at a desired depth of 35 to 50 mm. Typically, the drills will have steel V-shaped press wheels, steel flat press wheels, or rubber flat press wheels among others, all located behind the furrow openers. These drills will push or throw aside the dry surface-soil mulch to form V-shaped furrows with seed placement below the furrow bottoms.

Rain storms occurring after wheat planting can inhibit emergence because soil from the ridge and sides of the furrow will erode or slump into the bottom of the furrows. When this happens, the wheat plants must emerge through the normal planting depth plus the additional eroded soil deposition in the bottom of the furrow that may have also formed a surface seal or crust. Reduced populations of the remaining emerged wheat plants may reduce grain yields the following year.

Increasing intensity and duration of a rain storm increases the amount of soil slump into wheat furrows. High intensity storms generally pond water on the surface sooner, causing saturated soil surface conditions which reduce aggregate stability. Amount of soil eroded also increases generally with storm duration with rain intensity normally declining with time for the longer duration storms. Objectives of this research were to quantify any changes in wheat plant populations caused by 30 minutes of uniform sprinkler-applied simulated rain applied within four days after planting.

METHODS AND MATERIALS

The research was conducted in 1987 and 1988 during the normal winter wheat planting period of late September and early October at various locations within 10 km of the U.S. Central Great Plains Research Station near Akron, Colorado. Variables in this study were amount of applied water, residue level, tillage, planting depth, and soil texture. Soil texture and planting depth may also affect emergence. The soils, tillage treatments, residue levels, and planting depths are summarized in Table 1. The soils were described by Petersen et al. (1986). Planting depth was measured from the bottom of the furrows to seed placement. Disk treatment plots were actually sweep-plowed during the fallow period and then disked just before planting, which is a common practice. Check plots that received no simulated rain between planting and emergence were also included in the study. No natural precipitation occurred between planting and emergence.

A rainfall simulator similar to a design by Shelton et al. (1985), was used to apply different depths in 30 minutes, an arbitrarily selected time interval. Water application was monitored with a flowmeter to attempt to maintain approximate water application levels, but wind and humidity varied water application amounts somewhat between treatments. The simulator had nine spray nozzles arranged in a three by three array with variable spacing of approximately 2 m. Ground water was used to sprinkle the plots and the water had 350 ppm of total dissolved solids.

The simulator was operated at conditions that produce water drops with velocities and drop sizes similar to rainfall in the Central Great Plains (Shelton et al. 1985). The nozzles used were Spraying Systems Full-jet HH30WSQ which at low nozzle pressures of 14-20 kPa produce a range of drop sizes up to 6 mm. Application uniformity was measured and had Christiansen's (1942) Uniformity Coefficient between 70 to 90%. Water application amounts in the field plots were measured using four catch cans of 15 cm (6 in) diameter. Application amounts between 25 to 50 mm in 30 minutes were used, which correspond to 5 to 50 year annual-frequency storms, respectively (Hershfield 1961) in the U.S. Central Great Plains region.

Table 1. Site numbers, soils, tillage treatments, residue levels, and planting depths of the winter wheat emergence and rainfall plots.

Year	Site	Soil Texture	Tillage Treat.	Residue Level (kg ha^{-1})	Planting Depth (mm)
1987	1	Ascalon	no-till	5860	40—60
		sandy loam	clean-tilled	0	40—60
	2	Weld silt loam	disked	1790	40—60
1988	3	Ascalon	sweep-plowed	4880	40—60
		sandy loam	disked	2060	40—60

Winter wheat was planted at all sites with grain drills that had identical hoe-shoe furrow openers and either V-shaped steel or 75 mm flat rubber press wheels. Row spacing was 280 mm (11 in). The seeding rate was 51 kg ha^{-1} using "Carson" variety in 1987 and "TAM 107" in 1988. Both varieties have a medium-length coleoptile. Simulated rainfall was applied to all plots within 4 days after planting and emergence started seven to ten days after planting. Land slope at all sites was less than 0.5%. Almost all non-infiltrated water ponded in the furrows and eroded soil did not move laterally along the furrows.

Each time the rainfall simulator was set up, water was applied to two plots. One plot was seven furrows formed with the V-shaped press wheels adjacent to another plot which was seven furrows formed with the flat press wheels. The rainfall simulator was then moved a few meters to adjacent plots for the different combinations of application amount and tillage. Four replicated tests were made on each plot. Applied water depth was the average of depths collected in the four catch cans for each application. A diagram of the simulator nozzle array, plot layout and catch can location are shown in Figure 1. Plant populations were determined by counting the plants in a 1 meter length of the three middle rows of each plot.

RESULTS AND DISCUSSION

Winter wheat plant populations were reduced by the application of 30 minutes of simulated rainfall after planting. Increased application amounts caused a greater reduction of winter wheat plant populations. The use of flat press wheels with reduced tillage and increased surface residue increased plant emergence.

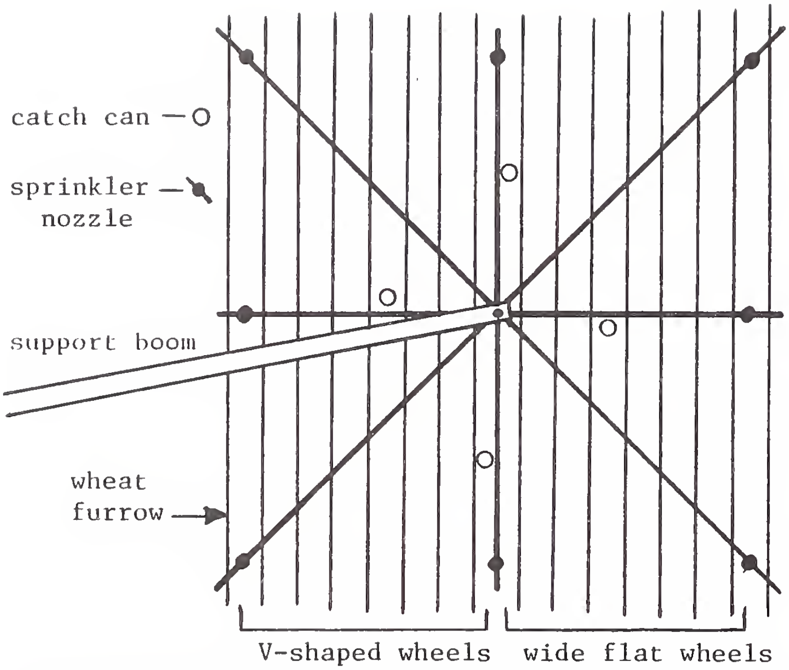

Figure 1. Rainfall simulator sprinkler array, plot layout and catch can location.

The 5860 kg ha^{-1} of crop residue on the soil surface after planting in 1987 or the firmer no-till soil conditions, and the flat press wheels improved plant populations significantly at site 1, as shown in Figure 2. The 1790 kg ha^{-1} of residue in the disked plots at site 2 also caused a lesser but still significant increase in populations over the clean-tilled or V- shaped press wheel plot. Wheat planted with the flat press wheels in the clean-tilled plots (no residue) on the Ascalon sandy loam had similar reductions in plant population to the plots planted with the V-shaped wheels. The shape and geometry of the furrows made by the flat press wheels in the clean-tilled plots were V-shaped and similar to furrows made with the V-shaped press wheels. The surface soil in the clean-tilled plots was so loose that soil moved by the hoe-shoe furrow openers fell back into the furrows behind the flat press wheels. Therefore, flat press wheels appear to have had no effect in changing the furrow geometry in clean-tilled soil with no surface residue after planting.

Planting with flat press wheels in no-till, firm soil conditions produced furrows in which the furrow bottoms were almost as wide and flat as the press wheels. The no-till soil conditions with surface residue and flatter-bottomed furrows reduced the amount of soil from the top and sides of the furrows that eroded into the furrow bottoms. The eroded soil was deposited over a wider area and consequently, left shallower soil deposition over the seed. This shallower soil deposition tended to be most shallow at the center of the furrow, where the drying soil crust would more easily crack and provide easier emergence. The V-shaped furrows did not exhibit this type of soil drying and cracking.

Statistical analysis was made of plant population after emergence among the different tillage and wheel treatments for the different water application levels. Duncan's Multiple Range Test (MRT) of plant population means at the 5% alpha level are shown in Table 2. The no-till, flat wheel treatment is significantly different for all

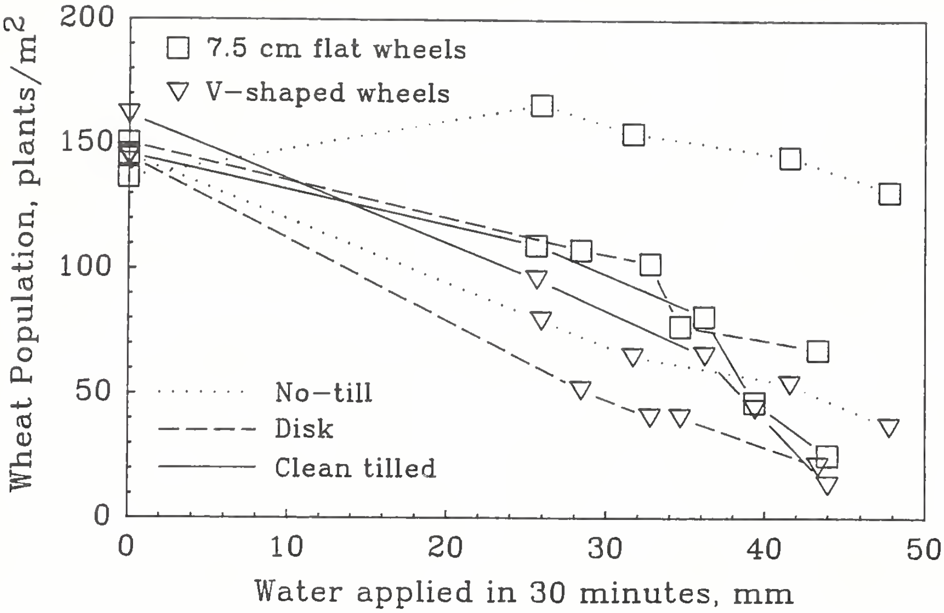

Figure 2. Winter wheat population versus water applied in 30 minutes for sites 1 and 2 from 1987.

treatments, and the flat wheel, disk treatment is significantly different from the V-wheel, disk treatment, for all water levels, so these two treatments will be treated separately. The other four treatments have population means not clearly different among the four water levels.

Plant populations after emergence in the check plots that received no simulated or natural rain were similar and averaged 147 plants m^{-2}. Plant populations on the no-till, flat press wheel plots with the 2 lowest water applications averaged 166 and 155 plants m^{-2}. The applied water may have increased seed germination more than reduced emergence caused by soil sedimentation into the furrow bottoms.

Plant populations (Fig. 3) on a Ascalon sandy loam soil in 1988 (site 3) were similar to those observed in 1987. Again, more surface residue and the use of the flat press wheels increased wheat populations. Average plant population in the dryland check plots was 147 plants m^{-2}. Plant populations for the V-shaped wheel plots and the lowest water application were not statistically different from flat wheel plots with the same tillage as shown in Table 3. However, the flat wheel plots had significantly greater plant population than the V-wheel plots for the same tillage, at the greater water application levels.

Two-year combined results from sites 1, 2, and 3 which had a planting depth of 40 to 60 mm are shown in Figure 4 for the 4 tillage and residue conditions. A single linear-regression line is shown and represents all plots planted with the V-shaped press wheels or in clean-tilled, no residue plots, and is

$$y = 151 - 2.62x, \; r^2 = 0.83 \qquad (1)$$

where, y = winter wheat plant population (plants m^{-2}); x = water applied in 30 minutes (mm); and r^2 = regression coefficient.

Table 2. Duncan's Multiple Range Test of plant population means to the various wheel type and tillage treatments at sites 1 and 2.

		Winter Wheat Plant Population after Emergence (plants m^{-2})							
		Average water (mm) applied in 30 minutes							
Tillage Trt.	Site	26.6		33.5		38.5		45.0	
Flat wheels									
No-till	1	166	a[1]	154	a	145	a	131	a
Disk	2	108	a	102	b	68	b	77	b
Clean-till	1	109	b	81	bc	46	bc	25	c
V—wheels									
No-till	1	79	bc	65	bc	54	b	37	c
Disk	2	51	c	40	c	21	cd	40	cd
Clean-till	1	96	bc	65	bc	44	bc	13	d

[1] *Means within a column that are followed by the same letter are not significantly different at the 5% level.*

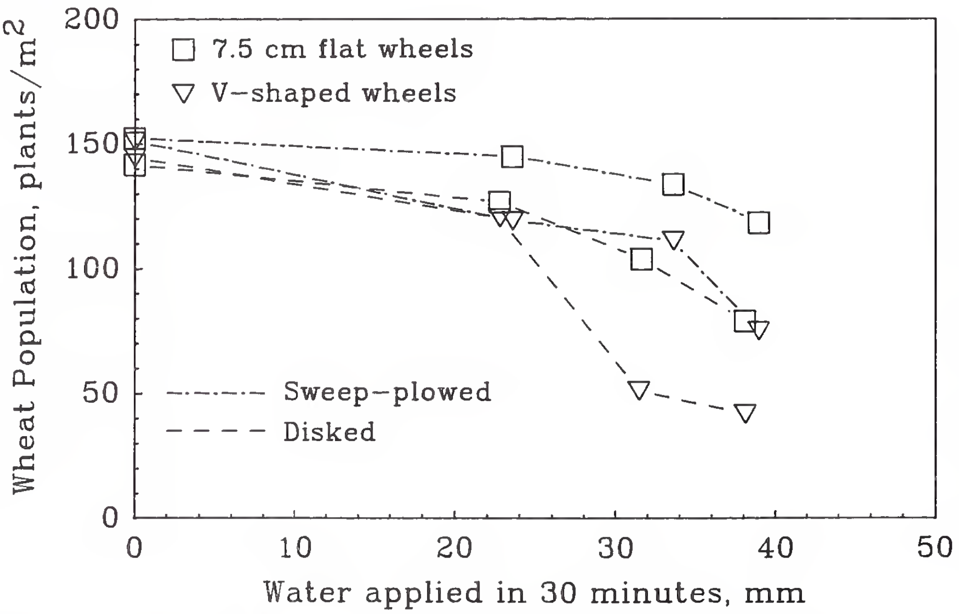

Figure 3. Winter wheat population versus water applied in 30 minutes for site 3 from 1988.

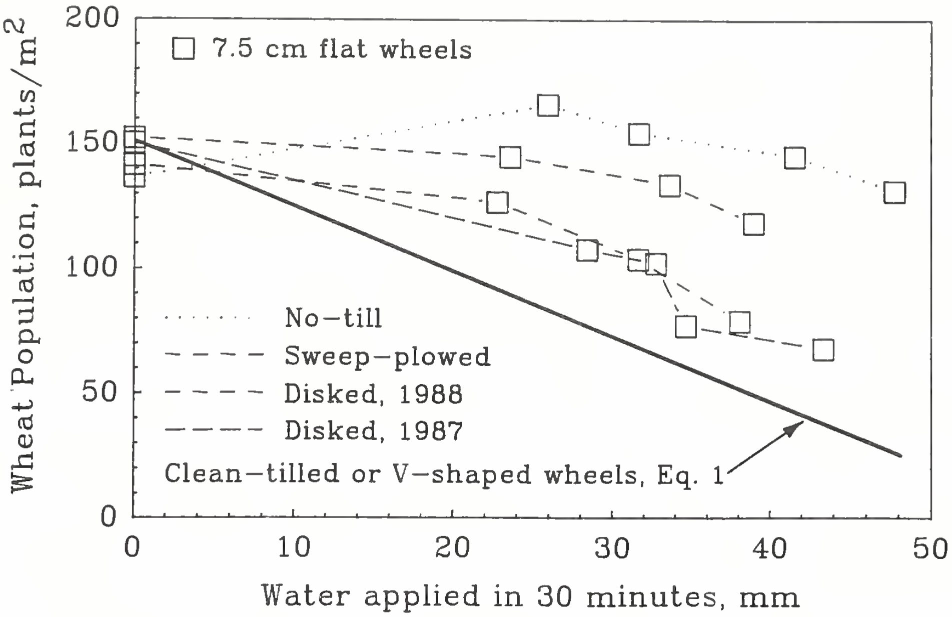

Figure 4. Combined winter wheat population versus water applied in 30 minutes for sites 1, 2 and 3 from 1987 and 1988.

Table 3. Duncan's multiple rage test of plant population means to the various wheel type and tillage treatments at site 3.

Tillage Trt.	Winter Wheat Plant Population after Emergence (plants m^{-2}) Average water (mm) applied in 30 minutes 23.1	 32.6	 38.5
		Flat wheels	
Sweep-plow	145 a[1]	154 a	145 a
Disk	127 a	104 a	79 b
		V—wheels	
Sweep-plow	119 a	111 ac	75 b
Disk	120 a	51 b	42 c

[1] *Means within a column that are followed by the same letter are not significantly different at the 5% level.*

The regression equation will be useful for predicting relative differences in winter wheat plant populations after 30-minutes rainfall in fields planted with V-shaped press wheels or clean-tilled fields. If predicted plant populations are low enough to greatly reduce yields, then the decision to replant could be made sooner than waiting for full emergence to occur. Knowing the relationship between plant population and final yield, a breakeven cost analysis can be made to determine what level of population loss in the fall is necessary to justify the cost of replanting.

Soil texture ranging from sandy loam to silt loam appeared to have little effect on wheat populations. Plant populations among the plots planted with V-shaped press wheels or in clean-tilled soil, and likewise among the disked plots with 1790-2060 kg ha^{-1} of residue show no significant difference between silt loam and sandy loam soils. Reduced tillage or increased surface residue appear to be the major factors that affect plant population for the same application depth.

SUMMARY AND CONCLUSIONS

Heavy rainfalls occurring within a few days after winter wheat planting significantly reduced wheat plant populations. A 30-mm rainfall in 30 minutes can reduce wheat populations by 50%. Wheat planted with more traditional V-shaped press wheels and wheat planted in clean-tilled, loose soil conditions exhibited significantly greater population reductions with increased water application after planting than plots with residue or planted with flat press wheels. A linear equation of plant population versus water application may be used to predict the decreased plant populations.

Use of wide flat press wheels in reduced-tillage conditions with surface residue significantly increased plant populations. How much of the population differences are due to tillage or due to residue is not known and should be a topic of future research. No-till plots with 5860 kg ha^{-1} of surface residue exhibited a population reduction only when water applications were greater than 40 mm in 30 minutes. Plots that were only sweep-plowed had slightly less plant populations than in no-till plots followed by plots that were sweep-plowed during the fallow season, then disked just before planting.

Reduced wheat emergence is a significant problem if heavy rains occur within a few days after planting. Wheat planted in fields with reduced tillage, increased surface residue and with wide flat press wheels will significantly increase wheat plant populations. If sprinkler irrigation is applied to germinating wheat to guarantee emergence, then flat press wheels should be used in combination with reduced tillage and surface residue.

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Response of Proso Millet to a No-Till Production System

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Anderson, R.L. 1991. Response of proso millet to a no-till production system. Pages 187-192 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

ABSTRACT

Proso millet (*Panicum miliaceum* L.) is well-adapted for the Central Great Plains and is commonly grown with a conventional mechanical tillage production system in a winter wheat (*Triticum aestivum* L.)—millet-fallow rotation. Research was conducted on a Weld silt loam (fine, montmorillonitic mesic Aridic Paleustoll) near Akron, CO to determine proso millet response to a no-till production system. Eliminating tillage increased proso millet grain yields and water use efficiency (WUE) over 20% compared to conventionally tilled proso millet production. Nitrogen fertilizer at 22 or 44 kg N ha^{-1} increased grain yields and water use efficiency of no-till proso millet regardless of whether precipitation received during the cropping season was 1% below (1985) or 33% below (1986) the long-term average for this location.

INTRODUCTION

The development of more efficient cultural practices for storing soil water during fallow periods has increased the potential for producers to grow two crops in three years in the Central Great Plains, rather than only one crop in two years. One successful two-crop-in-three-year scheme is winter wheat—proso millet-fallow (Anderson et al. 1986, Shanahan et al. 1988). The success of this rotation is increased when weed control is maintained during the fall after wheat harvest. Fall weed growth can consume 5 to 15 cm ha^{-1} of soil water (Greb 1979), and proso millet grain yield was increased 23% when fall weeds were controlled by sweep plowing (Anderson et al. 1986).

In the eastern part of the Central Great Plains, an ecofallow production system has been developed for a winter wheat—sorghum (*Sorghum bicolor* Moench.)-fallow rotation (Hinze and Smika 1983). Ecofallow relies on the use of herbicides for weed control, using minimal mechanical tillage. By eliminating tillage in the production system, wheat residue is maintained on the soil surface to suppress soil water evaporation from the soil surface (Greb 1983, Phillips 1984). This reduction of soil water loss by evaporation should supply more soil water for crop use, thus increasing the crop's water-use-efficiency (WUE). Another means to improve a crop's WUE is to apply N fertilizer to soils low in fertility (Greb 1983). Since water is the most limiting factor for plant growth in this semi-arid region (Greb 1983, Hinze and Smika 1983, Shanahan et al. 1988), any cultural manipulations which increase WUE should improve the probability of successful crop production during drought years. The objective of this study was to determine if eliminating tillage and applying N fertilizer would increase the efficiency by which proso millet converts a limited water supply into grain.

MATERIALS AND METHODS

The experiment was conducted on a Weld silt loam (fine, montmorillonitic, mesic Aridic Paleustoll) at Akron, CO. The soil contained 12 g kg^{-1} of organic matter and the pH was 7.0. The experimental design was a two-way factorial in a split plot arrangement, with the two factors being tillage system as whole plots and N fertilizer rates as subplots. Tillage systems compared were: (i) a conventional system of sweep plowing twice in the fall for weed control after wheat harvest, followed by spring disking to prepare a seedbed and (ii) a no-till system with herbicides providing weed control. In the no-till system, paraquat (1,1'- dimethyl-4,4'bipyridinium ion) at 0.28 kg ai ha^{-1} was applied twice in the fall after wheat harvest, and atrazine (6-chloro-N-ethyl- N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine) at 0.56 kg ai ha^{-1} was applied in April, approximately 60 days before planting proso millet. Herbicides were applied in 280 L ha^{-1} of spray solution with a 4 m boom sprayer. Three N levels were evaluated: 0, 22, and 44 kg N ha^{-1} as ammonium nitrate applied 30 days before planting. Fertilizer was applied by hand and incorporated by the spring disking in the conventional system, or remained on the soil surface with the no-till system. Plot size for each individual cell of a particular tillage by fertilizer treatment was 4 m by 4 m. All treatments were replicated four times.

'Cope' proso millet was planted 1 to 2 cm deep with a deep- furrow hoe drill at 11.2 kg ha^{-1} in 0.3-m rows on 7 June 1985 and 18 June 1986. Soil water content was determined gravimetrically for all treatments on three dates: (i) after wheat harvest, (ii) at proso millet planting, and (iii) after proso millet harvest. The sampling depth was 1.3 m, with two random samples collected per plot. Plant samples were harvested from 3 rows 1.2-m long in all plots to determine grain and straw yields and harvest index. WUE was calculated by dividing grain yield by crop water use (soil water use + crop season precipitation).

RESULTS AND DISCUSSION

No-Till vs Conventional Till Comparison

Eliminating tillage increased proso millet grain yields and WUE in both years (Table 1). The growing season (June 1 to Sept. 30) precipitation levels for the two cropping periods ranged from 67 (1986) to 99% (1985) of the 78-year average (212 mm), yet no- till proso millet yielded over 20% more than conventional-till proso millet in both years. This positive effect of eliminating tillage on grain yields was more pronounced during the dry year (1986), as grain yields were 34% higher with the no-till system. The harvest index was not affected by tillage system. Soil water storage by planting time was increased by eliminating tillage in 1985, but not in 1986.

Table 1. Effect of tillage system on soil water storage at planting time and agronomic response of proso millet grain production. Treatment means are an average of all N levels within each tillage system.

Tillage System	Soil-Water Storage $(mm\ (1.3\ m)^{-1})$	Grain Yield $(kg\ ha^{-1})$	Harvest Index[1]	Water-Use Efficiency $((kg\ ha^{-1})\ mm^{-1})$
		1985		
Conventional	150	2290	0.43	7.6
No-till	160	2730	0.42	8.9
F-test	*	**	NS	**
CV (%)	2.1	15.4	2.7	14.7
		1986		
Conventional	84	1200	0.44	7.9
No-till	86	1610	0.47	9.4
F-test	NS	**	NS	**
CV (%)	2.7	7.0	6.1	11.4

*, ** *Significant at 0.05 and 0.01 probability levels, respectively.*
NS—Not significant at the 0.05 probability level.
[1] *Harvest index = grain yield divided by above ground biomass.*

Nitrogen Fertilizer Effect on Proso Millet Production

Tillage system and precipitation level influenced proso millet response to N fertilizer. Grain yields were increased by N with both tillage systems in 1985 when precipitation was 99% of the 78- year average (Fig. 1). However, when precipitation was only 67% of the 78-year average in 1986, the addition of N increased grain yield only with the no-till system. Wheat residue on the soil surface reduces soil water evaporation (Greb 1983), which would provide more soil water for plant use in the no-till system and alleviate the water stress effect that occurred with conventionally tilled proso millet in 1986.

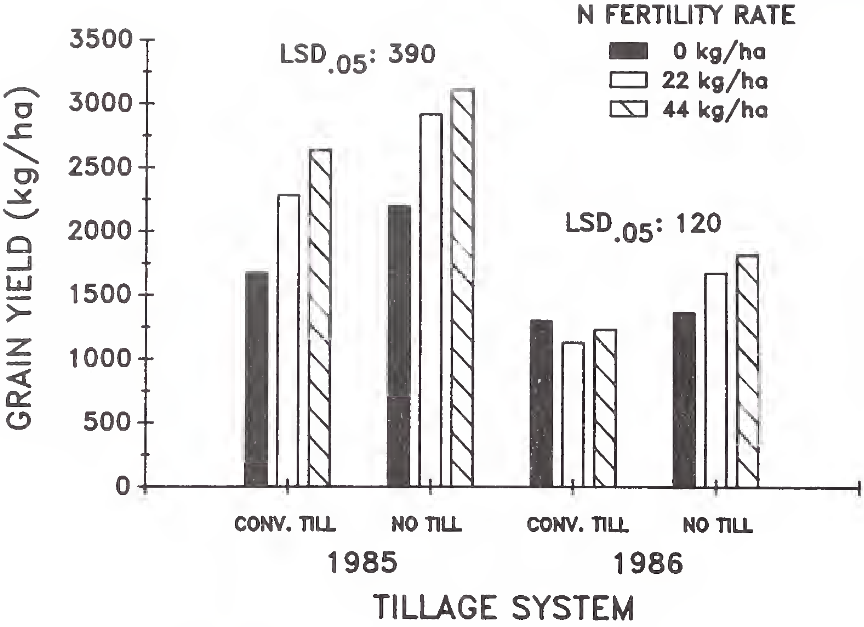

Figure 1. Effect on N fertilizer within each tillage system on grain yield of proso millet in 1985 and 1986.

Nitrogen fertilizer increased WUE of no-till proso millet in both years, but only in 1985 with the conventionally tilled proso millet (Fig. 2). During the dry year (1986), proso millet WUE in the conventional tillage system was not affected by N fertilizer, exhibiting the same response as shown with grain yields.

SUMMARY

Proso millet grain yields and WUE in the Central Great Plains were increased by more than 20% by eliminating tillage in the production system. Nitrogen fertilization at 22 or 44 kg N ha^{-1} increased grain yields and WUE of proso millet grown without tillage, thus, demonstrating the benefit of additional N in no-till production systems for proso millet in this area. The implementation of these two cultural practices, eliminating tillage and adding N, increased the effectiveness of proso millet converting the limited water supply into grain, and may decrease the probability of crop failure due to drought in this region.

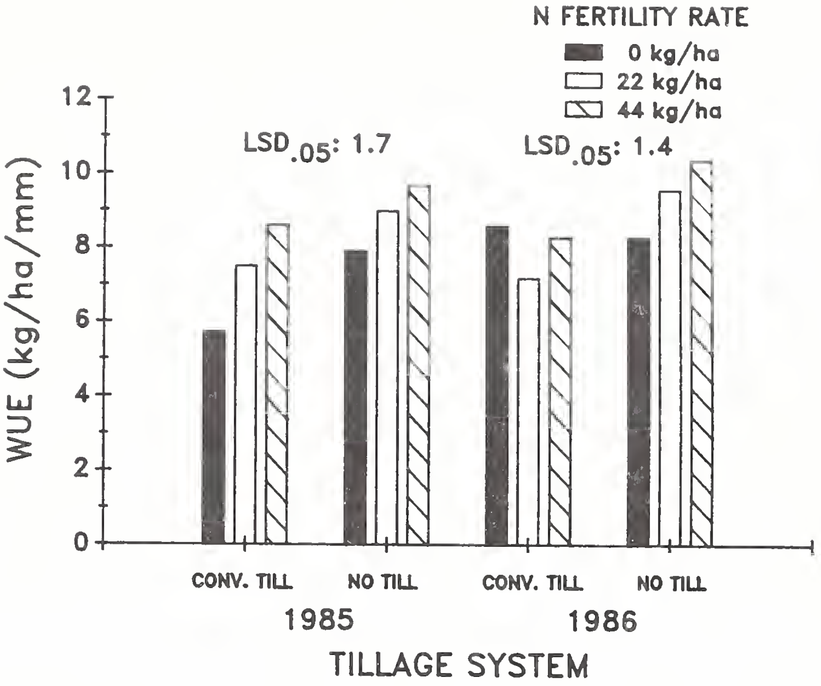

Figure 2. Effect of N fertilizer within each tillage system on water-use-efficiency (WUE) of proso millet grain production in 1985 and 1986.

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Allelopathic Activity in Rice (Oryza sativa L.) Against Ducksalad [Heteranthera limosa (Sw.) Willd.]

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ABSTRACT

Rice (*Oryza sativa* L.) is one of the leading food crops of the world. The value of rice production in the United States is about one-billion dollars annually. However, annual losses due to weeds in rice have been estimated at about 17% of the potential production or one million metric tons. More than 50 weed species infest drill-seeded rice in the U.S. and one of the most prevalent aquatic weeds is ducksalad [*Heteranthera limosa* (Sw.) Willd.]. During the summers of 1988 and 1989 field experiments were conducted to identify rice accessions from the USDA/ARS rice germplasm collection for allelopathic effects to ducksalad. Field experiments were conducted to evaluate about 10.000 accessions for allelopathic activity. Five to seven seeds of each rice accession were planted in hills about 75 cm apart in two replications. Allelopathic activity was recorded as 1) radius of the area affected by

allelochemicals from the base of the rice plant and 2) percentage of weed control within the affected area. Ducksalad was rated at the panicle initiation stage of rice development. Of the 10,000 accessions that were evaluated, 347 were identified as having evident allelopathic activity. Additional laboratory data demonstrated that allelochemicals that inhibit seed germination and radical growth of lettuce (*Lactuca sativa* L.), a common indicator plant, were present in rice straw of accessions that showed allelopathic activity in the field to ducksalad. The 347 accessions that demonstrated allelopathic activity in the field to ducksalad originated in 30 countries (Afghanistan, Argentina, Australia, Brazil, Columbia, Dominican Republic, France, India, Indonesia, Iran, Iraq, Israel, Italy, Japan, Malaysia, Mali, Mexico, Pakistan, People Republic of China, Peru, Philippines, Portugal, Republic of Korea, Soviet Union, Spain, Taiwan, Thailand, Turkey, United States and Vietnam).

INTRODUCTION

Rice is an essential food crop for most of the developing countries of the world. The United States has supplied between 17 and 28% of the world exports since 1970 (Smith et al. 1990). The value of rice production in the U.S. was estimated at about $1,090,000,000 in 1989 (USDA 1990). However, annual losses due to weeds in rice in the U.S. have been estimated at 17% of the potential production or about one million metric tons valued at $205 million (Chandler 1981). Rice is produced on about 1.05 million hectares in the U.S. with Arkansas, California, Florida, Louisiana, Mississippi, Missouri, and Texas producing virtually all of the rice in the U.S. Of these seven states, Arkansas leads the nation in rice production. In fact, Arkansas had about 43% of the rice acreage (500,000 hectares) and produced about 41% of the rice in the U.S. in 1989. The estimated value of the rice crop in Arkansas from 1986-89 was about $400 million annually (Chaney et al. 1989).

More than 50 weed species infest direct-seeded rice in the U.S. (Smith et al. 1977). Ducksalad is one of the most frequently reported aquatic weeds in rice (Chandler 1981, Smith et al. 1977). Effective weed-control programs for rice include preventive, cultural, mechanical, chemical and biological practices (Smith et al. 1977, Smith and Moody 1979). The most recent and perhaps least exploited is the biological method. In recent years the biological strategy of weed control, or more specifically weed control through allelopathy, has received increased attention. For example, it was estimated in 1977 that the development of new technology from allelopathics "would benefit U.S. agriculture by 2% of its total production, or about two billion annually" (USDA 1977).

In 1937, Molisch coined the term allelopathy and described it as any biochemical interaction among plants including micro-organism (Rice 1974). Although Molisch's definition includes both detrimental and beneficial interactions, allelopathy recently has been defined as any direct or indirect harmful effect by one plant on another through the production of chemical compounds released into the environment (Rice 1974). Allelopathy is postulated to be one mechanism by which weeds affect crop growth and occurs widely in natural plant communities (Bell and Koeppe 1972, Gressel and Holm 1964, Whittaker and Feeny 1971). Allelopathic potential of weeds through the release of toxic substances into the environment either through root exudation or from decaying plant material has been demonstrated in about 90 species (Putnam 1986). These weeds including quackgrass [*Agropyron repens* (L.) Beauv.] (Gabor and Veatch 1981, Kommedahl et al. 1959), yellow and purple nutsedge (*Cyprus esculentus* L. and *C. rotundus* L.) (Friedman and Horowitz 1971), Johnson-grass [*Sorghum halepense* (L.) Pers.] (Abdul-Wahab and Rice 1967), Canada thistle [*Cirsium arvense* (L.) Scop.] (Bendall 1975), leafy spurge (*Euphorbia esula* L.) (LeTourneau et al. 1956, LeTourneau and Heggeness 1957), giant foxtail (*Setaria faberii* Herrm.), yellow foxtail [*Setaria glauca* (L.) Beauv.], and crabgrass [*Digitaria sanquinalis* (L.) Scop.] (Schreiber and Williams 1967), velvetleaf (*Abutilon theophrasti* Medic.) (Elmore 1980), and tall fescue (*Festuca arundinacea* Schreb.) (Peters 1968 and Peters and Luu 1984). In addition to the existence of allelopathy in weeds, several workers have reported that crops such as rye (*Selecale cereals* L.) (Shilling et al. 1985), wheat (*Triticum aestivum* L.) (Shilling et al. 1985), sunflower (*Helianthus annuus* L.) (Leather 1983), and oats (*Avena sativa* L.) (Fay and Duke 1977) possess allelopathic activity or have weed suppressing properties.

Putnam and Duke (1974) postulated that "wild types" of existing crops may have possessed high allelopathic activity and this character was reduced or lost as they were hybridized and selected for other characteristics. Fay and Duke (1977) evaluated 3,000 accessions of *Avena* spp. germplasm for production of scopoletin (6-methoxy-7-hydroxy coumarin), a chemical identified as the allelopathic agent in a wide range of wild plants, and found that four accessions exuded up to three times as much as 'Garry', a standard oat cultivar.

The USDA/ARS National Small Grains Collection is located at Aberdeen, Idaho and contains a total of 108,933 accessions including *Triticum* (40,925), *Hordeum* (25,649), *Avena* (20,353), *Oryza* (16,008), *Secale* (2,304), *Tritico-Secale* (932), *Aegilops* (617) and others (169). The objective of this study was to evaluate germplasm accessions from the rice portion of the USDA/ARS National Small Grains Collection for allelopathic activity on ducksalad.

MATERIALS AND METHODS

Field Experiment

Field experiments were conducted in 1988 and 1989 to identify rice accessions possessing allelopathic properties to ducksalad as part of the USDA/ARS rice germplasm evaluation project at Stuttgart, Arkansas. Approximately 10,000 accessions, including checks, were seeded in hills in a 75 X 75 cm grid. Between 5 and 7 seeds were placed in hills in two replications from April 28 to April 30, 1988 and April 18 to April 20, 1989. The seedlings emerged between May 10 and May 12, 1988 and May 2 and May 4, 1989. The tests were conducted at the Rice Research and Extension Center, Stuttgart, Arkansas on a Crowley silt loam (fine montmorillonitic, thermic Typic Albaqualfs).

A natural infestation of ducksalad occurs at the Rice Research and Extension Center at Stuttgart; therefore, seeding the test with ducksalad was not necessary. Allelopathic activity to ducksalad was recorded in July in both 1988 and 1989, or at the panicle initiation stage, for most of the accessions. Two methods were used to record the activity: 1) the radical area (cm) from the base of the rice plant that was affected by allelochemicals, and 2) the percentage of weed control within the affected area. In the first method, actual measurements were made from the base of the plant to the outer most edge of the area of activity. The area of activity is defined as the area around the plant where no ducksalad growth appears or a reduced stand of ducksalad is present. The second method of measuring allelopathic activity is the reduction in the ducksalad population on a percentage basis compared to a control plant that has no affect on the ducksalad population.

A total of 82 kg N ha^{-1} as urea was applied to plots based on a 3-way split application. Thirty-one kg N ha^{-1} as urea were applied on June 14, 1988 and June 19, 1989 when the seedlings were at the 4th true leaf stage of development. The remaining 41 kg N ha^{-1} were applied in equal increments on July 7. 1988 and July 17, 1989 and 12 days later in both years. The tests were irrigated two times in May in both 1988 and 1989 to insure uniform seedling emergence. A permanent flood was applied in June in both 1988 and 1989.

Plant height (cm), days to maturity, plant type, panicle type, hull cover or pubescence, hull color, lemma color, awning, lodging and grain type were recorded for each accession. Plant height was measured in cm from ground level to the center of the mature panicle. Maturity was determined by calculating the number of days from the date of seedling emergence to the date that 50% of the panicles had emerged. Plant type, hull cover, hull color, lemma color and awning were recorded in the laboratory after threshing. The accessions were characterized as having extra long (>7.50 mm), long (6.61-7.50 mm), medium (5.51-6.60 mm) or short grain (<5.50 mm).

Laboratory Experiment

Rice straw was collected from 26 accessions, including checks, in November, 1989 based on allelopathic activity of the lines from field tests conducted in 1988 and 1989. The 26 accessions were separated into three groups possessing high (radius of more than 15 cm), medium (radius of 10-15 cm) and no (radius of less than 10 cm) allelopathic activity. The straw was dried at 60°C for 24 hours and ground. One hundred grams of the dried sample was added to 1 liter of distilled water and homogenized with a blender for 10 minutes. The mixture was filtered and the filtrate was considered as full strength, or 100% concentrate, and the supernatant was lyophilized.

Twenty lettuce seeds, 1 ml extract solution, and 0.15 ml Vitavax 200 fungicide (3:400 v/v) were placed on filter paper (9 cm^2) in petri dishes. Extracts were diluted with distilled water so the final concentrations were 25%, 50%, and 100%. An untreated check solution (distilled water) was included. The petri dishes were incubated at 25°C in a germinator for five days and the germination percentage and radical length were determined. The experimental design was a complete randomize designed with 4 replications and the test was repeated once.

RESULTS AND DISCUSSION

Field Experiment

Field data from the 1988 replicated test demonstrated that 191, or about 3.8% of the 5,000 accessions, had a radius of activity greater than 10 cm to ducksalad and these accessions were significantly different from the check plants that demonstrated no allelopathic activity. Furthermore, field data from the 1989 replicated test demonstrated that an additional 156 accessions, or about 3.1%, from a completely different set of 5,000 accessions had a radius of activity greater than 10 cm to ducksalad. Nine accessions that had a radius of activity of 17 cm or greater and a percent weed control of 70% or greater are shown in Table 1. The accessions that demonstrated allelopathic activity in 1988 and 1989 originated in 30 countries (Afghanistan, Argentina, Australia, Brazil, Columbia, Dominican Republic, France, India, Indonesia, Iran, Iraq, Israel, Italy, Japan, Malaysia, Mali, Mexico, Pakistan, Peoples Republic of China, Peru, Philippines, Portugal, Republic of Korea, Soviet Union, Spain, Taiwan, Thailand, Turkey, United States, and Vietnam). Also, the 347 accessions, from a total of about 10,000 accessions, that demonstrated allelopathic activity to ducksalad in 1988-89 were genetically diverse for other plant characteristics. For example, days from emergence to anthesis ranged from less than 60 days to greater than 140 days, plant height ranged from less than 79 cm to greater than 160 cm, grain type included short (<5.50 mm), medium (5.51-6.60), long (6.61-7.50 mm) and extra long (>7.50 mm) kernels and most of the genotypes demonstrated no lodging or few plants were leaning. Although correlation coefficients were not calculated for allelopathic activity versus agronomic characteristics the agronomic characteristics are important in selecting parents for varietal development programs.

Table 1. Origin, plant height, grain type, days to maturity and seed coat color of nine germplasm accessions and two cultivars (Paloryma and Rexmont) that demonstrated allelopathic activity to ducksalad.

Germplasm Identification	Country of Origin	Radical Mean Activity	Percent Weed Control	Plant Height (cm)	Grain Type[1]	Days to Maturity[2]	Seed Coat Color[3]
Taichung Native 1	Philippines	18	85	91	S	102	Lt. Br.
Shuang-Chiang-30-21	Taiwan	18	85	92	M	91	Lt. Br.
India AC 1423	India	18	85	128	M	115	Red
Woo Co Chin Yu	Taiwan	18	80	154	L	113	Lt. Br.
CICA 4	Brazil	18	70	101	S	112	Lt. Br.
IR 781-497-2-3	Philippines	17	90	91	M	114	Lt. Br.
NSSL 10/28 STP 8	U.S.	17	85	136	L	90	Lt. Br.
TONO Brea 439	Dom. Rep.	17	85	160	L	137	Lt. Br.
T65/2X-TN-1	Philippines	17	85	103	S	103	Lt. Br.
Control							
Paloryma	U.S.	0	0	116	M	88	Lt. Br.
Rexmont	U.S.	0	0	89	L	87	Lt. Br.
LSD (0.05)		7	17	20		8	

[1] *Grain type: S = short, M = medium and L = long*

[2] *Days to maturity: From seedling emergence to 50% of the panicles emerged*

[3] *Seed coat color: Lt. Br. = Light Brown*

Laboratory Experiment

Paloryma and Rexmont are two germplasm accessions that did not show allelopathic activity in the field in 1988 or 1989; whereas, IR 781-497-2-3 and T65/2X-TN-1 are two accessions that are derivatives of Taichung Native 1 and these accessions demonstrated a high level of allelopathic activity in the field in both 1988 and 1989. Lettuce was used as an indicator plant and almost 99% of the lettuce seed germinated in the control (distilled water) petri dishes (Table 2). However, the germination percentage of lettuce seed in a 25% filtrate concentration from Rexmont, Paloryma, T65/2X-TN-1 and IR 781-497-2-3 was 96, 94, 16, and 3% respectively. Furthermore, the germination percentage of lettuce seed in a 100% filtrate concentration from Rexmont, Paloryma, T65/2X-TN-1 and IR-781-497-2-3 was 76, 67, 0, and 0%, respectively.

Table 2. Comparison of allelopathic activity of extracts (straw-water filtrate) from two germplasm accessions and two cultivars (Rexmont and Paloryma) on germination and radicle growth of lettuce at different concentrations (0, 25, 50, and 100%).

Concentration	Designation	Seed Germination (%)	Radical Length (mm)
100	Rexmont	75.6	159
	Paloryma	66.9	89
	T65/2X-TN-1	0.0	0
	IR 781-497-2-3	0.0	0
	LSD (0.05)	8.4	24
50	Rexmont	93.7	417
	Paloryma	88.8	356
	T65/2X-TN-1	7.5	4
	IR 781-497-2-3	4.4	1
	LSD (0.05)	6.9	41
25	Rexmont	95.6	536
	Paloryma	94.4	448
	T65/2X-TN-1	16.3	9
	IR 781-497-2-3	3.1	1
	LSD (0.05)	8.1	42
0	Distilled water	99.0	485

The growth and development of the radical of lettuce was also affected by the filtrate. For example, the radical length of lettuce in the control (distilled water) was 485 mm. The radicle length of the lettuce from extracts of Rexmont, Paloryma, T65/2X-TN-1 and IR-781-497-2-3 in a 25% concentration was 536. 448. 9 and 1 mm, respectively; whereas, the radical length of the four accessions was 159, 89, 0 and 0 mm at 100% concentration, respectively.

CONCLUSIONS

Approximately 3.5% of the 10.000 rice accessions that were evaluated for allelopathy to ducksalad demonstrated some allelopathic activity. A 3.5% frequency rate suggests that about 500 accessions in the rice collection produce some allelochemicals to ducksalad. The 347 accessions that demonstrated allelopathic activity also exhibited genetic diversity for plant characteristics such as plant height, maturity, grain type, plant type, hull cover. hull color and culm strength. Laboratory data demonstrated that allelochemicals that inhibit seed germination and radicle length of lettuce, a common indicator plant, were present in rice straw of accessions that showed allelopathic activity in the field to ducksalad. Tests to isolate and identify the allelochemicals that are responsible for the allelopathic activity are presently being conducted.

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Responses of Blue Grama Photosynthesis, Water Use, and Leaf-Chlorophyll Concentration to Atrazine

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ABSTRACT

The *s*-triazine class of compounds are effective herbicides because of their inhibitory effect on photosynthetic electron transport, but they have also been reported to act as growth regulators in some species when applied at low concentrations. Several researchers have reported that atrazine and other *s*-triazine herbicides increase productivity of warm-season range grasses, although the fundamental mechanism behind this response is unknown. This study was undertaken to investigate the photosynthetic response of blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.), the dominant species of the Great Plains, to regulated doses of low-concentration atrazine solution. We hypothesized that increases in growth of blue grama from low concentrations of atrazine would result via a growth regulator-like stimulation of photosynthesis. Greenhouse-grown, potted blue grama plants were transferred to a high light intensity growth chamber a week prior to measurements. Half of the plants were watered with solution containing 1.25 μg atrazine ml^{-1} water and the other half (controls) with tap water. Whole-plant photosynthesis of atrazine-treated plants declined relative to the control plants during the atrazine application period, but showed signs of recovery when atrazine application ceased. Single leaf, intercellular CO_2 response curves of photosynthesis indicated inhibitions of photosynthetic light reactions from the atrazine applications, despite atrazine-induced increases in leaf-chlorophyll concentrations. These results indicate inhibition of blue grama photosynthesis to atrazine consistent with its reported inhibitory effect on electron transport. We conclude that reported beneficial effects of atrazine on rangeland blue grama production do not arise from an initial stimulation in photosynthesis, and hypothesize that adaptive benefits may arise indirectly from stress-induced water conservation or from latent stimulations in photosynthesis after inhibitory herbicidal effects of atrazine subside.

INTRODUCTION

The *s*-triazine herbicides inhibit photosynthetic electron transport, although a wide range of tolerances to the triazines are known to exist among plants (Ebert and Dumford 1976). When applied at "sub-lethal" concentrations they often behave as growth-regulating agents and have been reported to enhance yield and N content of treated plants (Ebert and Dumford 1976. Fedtke 1982, Ries 1976). Higher protein and chlorophyll contents as well as enhanced photosynthetic activity have also been observed in response to sub-lethal concentrations of the herbicides. However, Fedtke (1982) observed that reports of higher protein concentrations of treated plant tissue are usually associated with lower yields. This would suggest that triazine-induced concentration of plant protein is a stress response. The increase in protein concentration could simply be a passive, reduced-growth response caused by inhibited photosynthesis. However, metabolic shifts in triazine-treated plants indicative of increased nitrate reductase activity and amino acid synthesis may occur (Fedtke 1982).

Range scientists have long been aware of the potential beneficial uses of atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine] for stimulating yield and protein content of range grasses (Baker et al. 1980, Houston and Van Der Sluijs 1973, Houston and Van Der Sluijs 1975, Hyder and Bement 1964, Kay 1971, Rehm 1984). However, the fundamental mechanisms for observed plant responses to atrazine in range systems are poorly understood. Hyder et al. (1976) demonstrated that atrazine prevented thinning of blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) stands during a drought, and suggested this response was the result of reduced transpiration of atrazine-treated plants, although they did not measure transpiration of blue grama. Their conclusion was based on the work of Smith and Buchholtz (1962, 1964) and others who had previously shown that atrazine reduces plant transpiration in other species. This apparent "stress" response would presumably be beneficial for maintaining grass stands in semi-arid environments by metering water consumption and thereby conserving soil water. However, in more recent work, Rehm (1984) found atrazine-induced stimulation of growth of warm-season grasses occurred in years when water was more plentiful. Atrazine had no effect on forage yields in dry years. In none of these range studies has it been possible to separate the stimulatory effect of atrazine on forage growth from benefits resulting from weed control, although in several studies, yields of total plant matter treated with atrazine (mostly forage) exceeded control yields (forages plus weeds). Further, the response of vegetation to atrazine is inconsistent, particularly in field environments, discouraging practical applications. Basic studies are needed to elucidate the mechanisms of plant responses to atrazine to insure efficient use of the herbicide on rangelands.

The purpose of this investigation was to evaluate the response of photosynthesis and water loss of blue grama, the dominant C_4 range grass of the Great Plains, to small, regulated doses of atrazine applied to the soil of potted plants. No information is currently available on the response of blue grama gas exchange to atrazine.

MATERIALS AND METHODS

Plant Culture

Crowns of eight blue grama plants selected from a nursery at the USDA-ARS Central Plains Experiment Range near Nunn, Colorado were transplanted in October 1987 to pots (15-cm inside diameter top by 10.7-cm bottom by 13.6-cm height) containing an Ascalon fine sandy loam (fine-loamy mixed, Mesic Aridic Argiustoll) soil. Organic carbon content of the Ascalon soil is 8 g kg^{-1} and pH is 6.2. The plants were selected based on similar morphological appearances. Previous cytological work (McGinnies et al. 1988) had established that all eight plants were tetraploid. The plants were grown in the greenhouse, and then transferred to a high-light intensity EGC[6] (Chagrin Falls, Ohio) growth chamber on day of the year (DOY) 80 for one week of acclimation before measurements began. The plants were watered infrequently in the greenhouse and therefore grew slowly. Once in the growth chambers, plants were watered every two or three days and a water budget was maintained. Photosynthetic photon flux density in the growth chamber at plant height was 1400 μmol m^{-2} s^{-1} during the 16-h photoperiod. Half of the plants were designated atrazine-treated plants (A) and were watered frequently with 100 ml of an atrazine solution containing 1.25 μg ml^{-1}. Tap water was additionally added to meet consumptive water use plus evaporation. The remaining plants (C-treatment) were watered similarly to the A-plants, but with tap water only. No fertilizer was added to the pots. Some studies (Cervelli et al. 1982, Theodorou and Sands 1980) have indicated that plant responses to atrazine involve changes in nutrient availability resulting from direct microbial responses in soil to atrazine; we did not want to confound interpretation of plant responses by adding readily available nutrient sources. Between DOY 88 and 113, 1800 ml of the atrazine solution had been added to A-pots, for a total of 2.25 mg atrazine pot^{-1}, or 966.5 μg atrazine kg^{-1} soil. This rate is similar to those used in field applications on the short-grass range (Houston 1977, Hyder et al. 1976). Atrazine applications were discontinued from DOY 113 through the end of the study, although pots continued to be well-watered. One of the pots selected for the A-treatment was discarded before the first atrazine dose was administered because of poor plant performance.

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[6] Trade names are included in the text as a convenience to the reader and do not constitute any preferential endorsement by USDA-ARS of these products over other similar products.

Every week during the period when gas exchange measurements were performed (see below), all plants were clipped back to a height of 30 cm. This was required so plants would fit into the gas exchange cuvette, and generally removed only a few cm height of plant tissue.

Whole-Plant Gas-Exchange Measurements

Steady-state measurements of whole-plant CO_2 exchange rate (CER) and pot evapotranspiration (ET) were made periodically (15-different days between DOY 87 and 139 see Fig. 1 and 2) by placing pots underneath a 1000 Watt metyl-halide lamp and placing a cylindrical, plexiglass cuvette (500-mm height by 210-mm outside diameter) over the pots, sealing at the rim of the pots. Outside air was drawn through the cuvette with a pump at the rate of 33 l min^{-1}, resulting in a cuvette air exchange rate of approximately two volumes per minute. A fan positioned in the top of the cuvette maintained constant turbulence during measurement. Sub-samples of air entering and exiting the cuvette were diverted through an EG&G dew point hygrometer (Model 911 EG&G International, Waltham, MA) and an ADC (Hoddesdon, England) infra-red gas analyzer for determinations of airstream [H_2O] and [CO_2], respectively. Transpiration and CER were calculated on a per pot basis from measurements of the differential of the respective component gas concentrations across the cuvette and the gas flow rate.

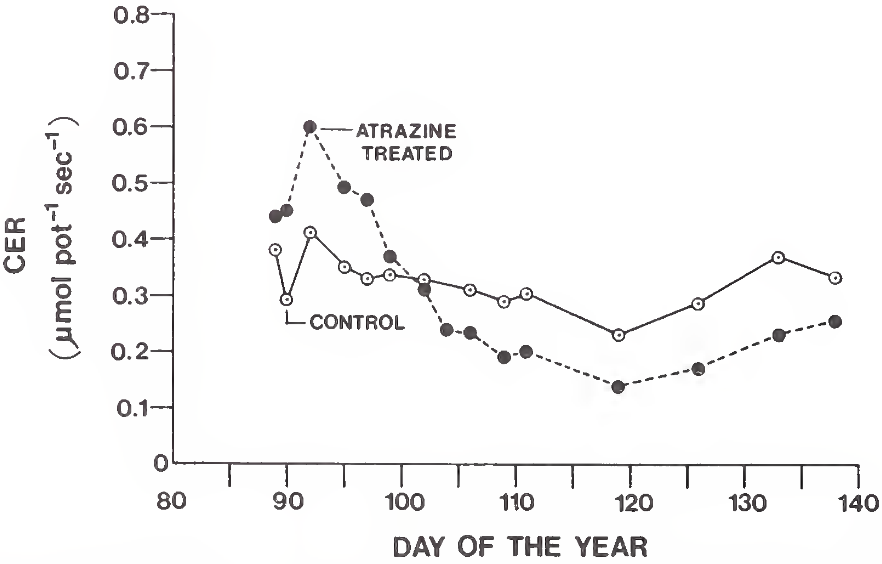

Figure 1. Whole-plant carbon dioxide exchange rate (CER) of atrazine treated blue grama for discrete measurement dates.

Photosynthetic photon flux density at the top of the cuvette during measurement was approximately 800 μmol m^{-2} s^{-1}, and air temperature inside the cuvette varied from 27 to 31°C. From 30 to 60 minutes were required after each pot had been placed in the cuvette for steady-state gas exchange to be realized and, therefore, measured. All pots were measured between mid-morning to early-afternoon on the same day.

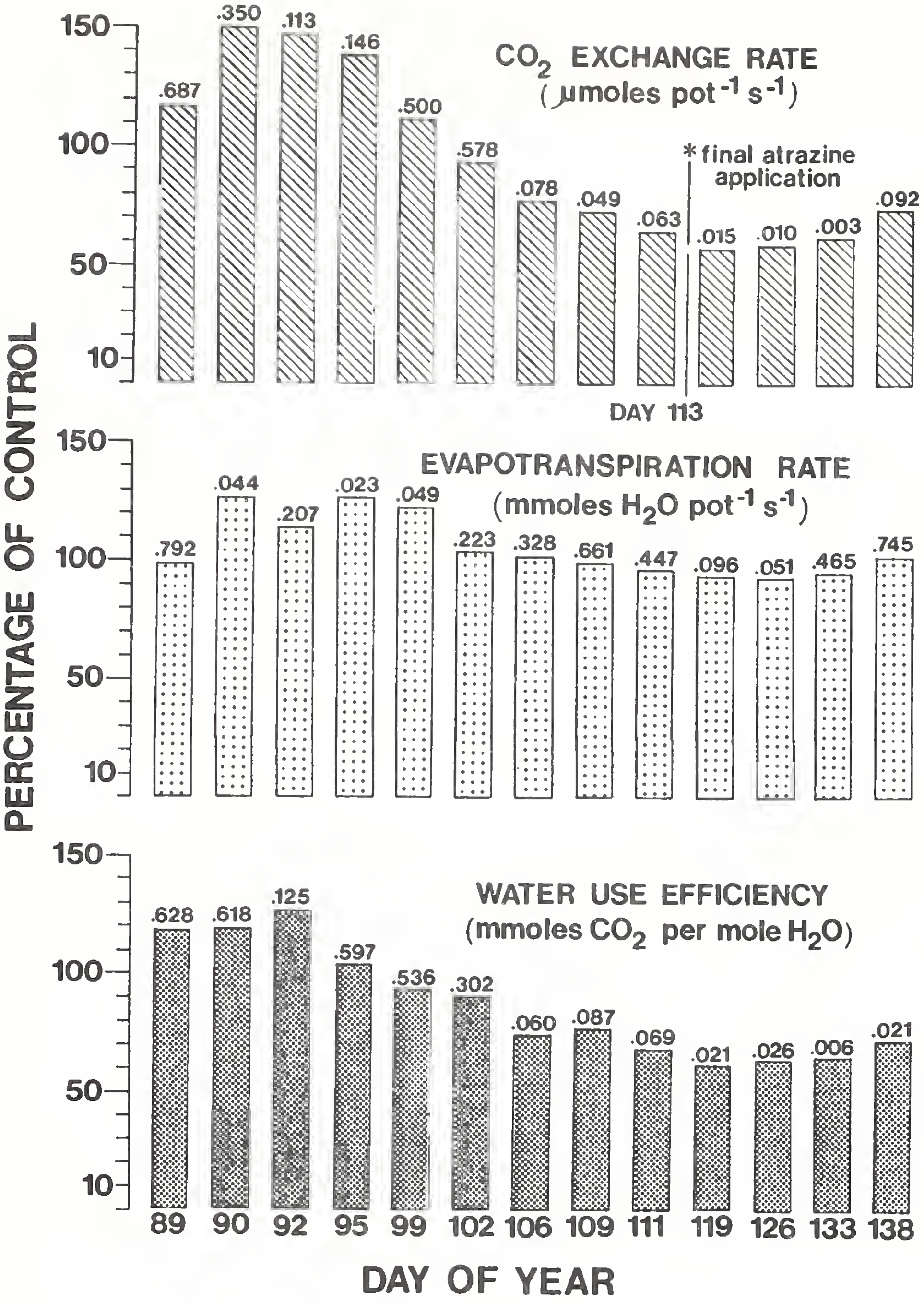

Figure 2. Whole-plant carbon dioxide exchange rate, evapotranspiration rate and water-use efficiency of atrazine-treated blue grama expressed as a percentage of control for discrete measurement dates. Numbers given above columns are probability levels for significant differences between controls and atrazine-treated plants.

Single Leaf CER

On DOY 113, when atrazine effects on whole-plant CER were most severe (40% reduction compared to control plants), mid-sections of two recently, fully-expanded leaves from each pot were sealed in a single-leaf cuvette for measurements of single leaf CO2 exchange rate (CERL) at a range of [CO2]. Different measurement [CO2] were obtained from premixed bottled gasses. Approximately 30 minutes acclimation at each [CO_2] was required for every CERL measurement. The ADC (Hoddesdon, England) Photosynthesis System was used for measurements of CERL. Intercellular CO_2 concentrations (C_i) were calculated according to Farquhar and Sharkey (1982), and were used to construct C_i-response curves of CERL for both treatments.

Leaf-Chlorophyll Concentrations

On DOY 126, representative lamina were excised from the plants and assayed for chlorophyll concentration according to Hiscox and Israelstam (1979).

Soil Atrazine Concentrations

Two soil cores per pot were mixed and 100-gram subsamples tested for atrazine. Soil was extracted into dichloromethane by sonication (EPA, SW846 method 3550). Analysis of extracts was by gas chromatography (Tracor model 340, Austin, TX) using a Tracor model 702 nitrogen-phosphorus detector. A 15-m by 0.25-mm I.D., SPB-5 fused silica, capillary column (Supelco, Belafonte, PA) was used for analytical separation. Operating temperatures for the injector, detector and oven were, respectively, 215, 250 and 50—250°C with an oven ramp-rate of 10°C min^{-1}.

RESULTS AND DISCUSSION

Photosynthetic and Chlorophyll Responses

Mean CERs were greater for the A-plants compared to the C-plants from DOY 89 through 99 (Fig. 1). The A-plants were, however, visually larger at the beginning of the experiment, a bias which would tend to result in higher rates for the A-treatment. However, statistical comparisons between the relative responses of CER were not significantly different during this period (Fig. 2). Over the period from DOY 92—119, atrazine-treated plants exhibited a continual, rapid decline in CER (Fig. 1 and 2). A moderate decline was noted for the control plants. Whole-plant CO_2 exchange rates of the A-plants declined to 60% of the C-plants by DOY 119, with significantly ($P<0.05$) lower CER noted on four of five measurement days between DOY 109 and 133 (Fig. 2).

Following the final atrazine application (DOY 113), no further decreases in photosynthesis rates of the A-plants relative to controls were observed (Fig. 2). Slight increases in photosynthesis rates of A-plants relative to controls were evident on the final two measurement days of the study (DOY 133 and 138).

Carbon dioxide exchange rates of the C-plants were fairly stable throughout the study. This stability was partly due to weekly clipping of the plants (see Materials and Methods) which reduced phytomass accumulation and therefore prevented the generation of a considerably larger photosynthetic surface as the study progressed. Detling (1987) reported that partial defoliation of blue grama initially reduces whole-plant photosynthesis, followed by increased photosynthetic activity due to generation of young, photosynthetically-efficient leaves. Such fluctuations in whole-plant photosynthetic activity due to defoliation were likely minor in the present study because of the small amounts of tissue removed. Frequent watering of the pots and failure to add fertilizer (see Materials and Methods) may have resulted in N shortages, which in turn would have reduced photosynthesis (Brown 1978). Accumulation of old phytomass as the plants aged would also contribute to decreased photosynthetic capacity of the remaining tissue.

Leaf-chlorophyll concentrations of A and C leaves on DOY 126 were 48.7 μg cm^{-2} and 25.7 μg cm^{-2}, respectively, a difference that was highly significant ($P<0.01$) as determined by t-test. The atrazine-treated plants were noticeably greener than controls. These results confirm previous observations of the "greening" effect of s-triazine herbicides (Ebert and Dumford 1976).

Intercellular CO_2-response curves of CERL performed on DOY 113 (Fig. 3) when responses of CER to atrazine were greatest (Fig. 2) show strikingly different patterns for the two treatments. The initial slope of the curve appears considerably less for the atrazine-treated leaves, and CERL of A leaves is saturated with respect to C_i at approximately 100 μmol CO_2 mol^{-1} air. In contrast, CERL of control leaves is still limited by C_i up to 170 μmol CO_2 mol^{-1} air. According to the analysis of such curves by Farquhar and Sharkey (1982), these results indicate that both carboxylation capacity and light reactions are severely inhibiting photosynthetic capacity of atrazine-treated leaves. This inhibition is consistent with the disruption of photosynthetic electron transport by atrazine (Ebert and Dumford 1976), and explains reductions in CER.

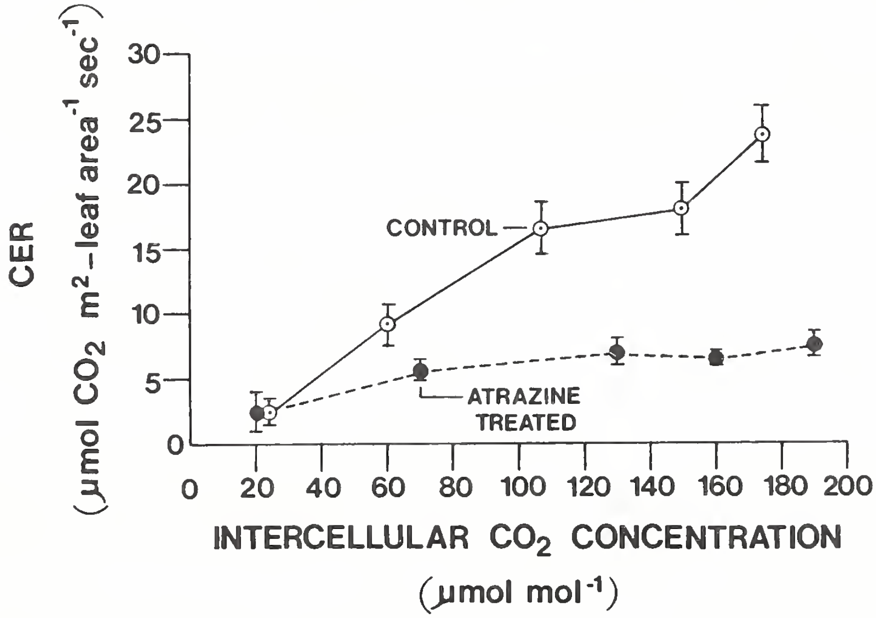

Figure 3. Intercellular carbon dioxide response curves of single leaf CER of atrazine-treated and control plants.

Increased growth of atrazine-treated blue grama plants in the field is difficult to explain from the data of this experiment as our results collectively demonstrate decreased photosynthetic activity in blue grama plants in response to the atrazine applied. Stimulation of photosynthesis from exposure of plants to *s*-triazine herbicides seen in other work (Chernyad'ev et al. 1986) is apparently not a factor in blue grama. Despite greening of the atrazine-treated leaf tissue and increased chlorophyll concentrations, inhibition of photosynthetic electron transport apparently initially limits blue grama photosynthetic activity. Stimulation of photosynthetic activity by *s*-triazine herbicides in some plants may occur when one of several possible resistant mechanisms to toxic effects of the herbicides (Ebert and Dumford 1976) are operative; our results would suggest these mechanisms are apparently lacking in blue grama. Photosynthesis of the resistant plant is then stimulated by an increase in leaf N concentration (Brown 1978) which usually accompanies atrazine application. In the case of blue grama, any such stimulation would have to take place after the deleterious effects of atrazine had subsided. It is noteworthy that deleterious effects of atrazine on CER ceased immediately following termination of atrazine application, and that potential recovery of the A-plants was observed. Further study will be required to determine whether this recovery can eventually result in a photosynthetic advantage for the atrazine-treated plants.

Evapotranspiration and Consumptive Water Use

Evapotranspiration rates appeared generally unaffected by the atrazine treatment (Fig. 2). Water-use efficiency, calculated as the ratio of CER/ET, was greater for control "pots" when atrazine responses of CER were greatest (Fig. 2). These results do not necessarily indicate that WUE of the control "plants" was greater. The frequent watering regime resulted in a damp soil surface which likely contributed significantly to water vapor exchange. For this reason, much of the pots' evapotranspiration was due to soil evaporation.

Water loss per pot (cumulative evapotranspiration) was lower for A-plants from DOY 118—140 (Fig. 4). These results indicate reduced transpiration for the A-treatment over the period following withdrawal of atrazine application, and are consistent with other observations of atrazine-mediated reductions in plant transpiration (Smith and Buchholtz 1962, Smith and Buchholtz 1964). The results also support Hyder et al. (1976) who suggested that atrazine increases drought resistance of blue grama by reducing transpiration. Inability to detect this effect in the gas exchange data (Fig. 2) may be due to the timing of those measurements. Photosynthesis and ET were determined several hours following irrigations to prevent confounding treatment effects with plant responses to water stress; an apparent large contribution of soil evaporation to pot ET at these times may have prevented seeing any differences in ET.

Soil Atrazine Concentrations

A total cumulative concentration of 967 μg atrazine kg^{-1} was delivered to the atrazine-treated pots. At the termination of the experiment (DOY 140), a mean concentration (n=3) of 123.5 ± 16.9 μg kg^{-1} was extractable from the soil. The total concentration of atrazine remaining in the soil is unknown because the bound fraction (i.e., adsorbed to clay and organic matter fractions) is not liberated during the

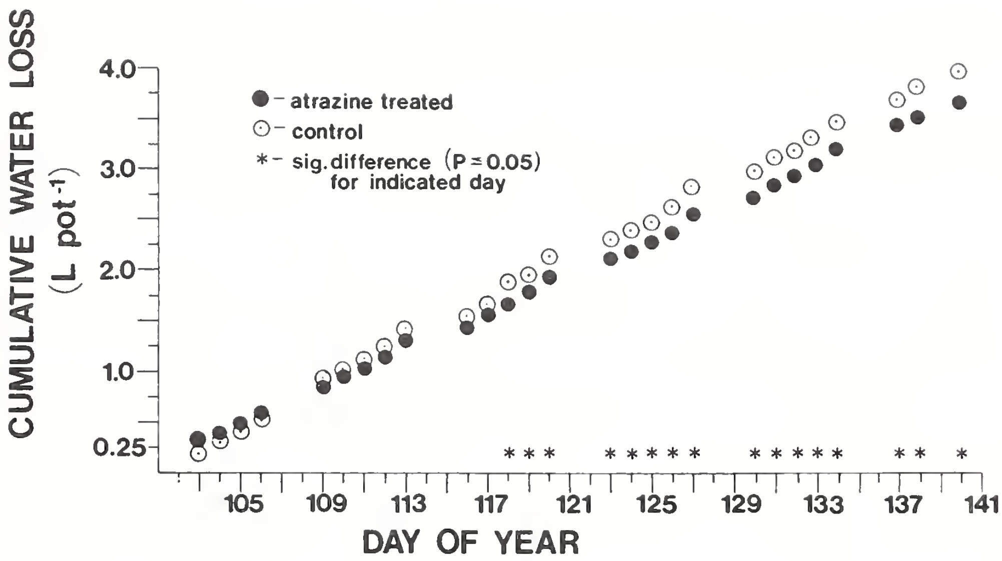

Figure 4. Cumulative water loss per pot for atrazine-treated and control blue grama plants for the period just prior to and following atrazine application.

extraction procedure. There was no drainage in this study and thus no leaching losses of atrazine. Atrazine volatilization was assumed to be inconsequential. Therefore, we cannot evaluate the rates of atrazine degradation in the soil with confidence.

SUMMARY

Dilute concentrations of atrazine applied periodically to the soil of potted blue grama plants reduced whole-plant photosynthesis and consumptive water use, although leaf-chlorophyll concentrations were increased. Intercellular CO_2 response curves of leaf photosynthesis indicate that atrazine applications inhibited photosynthetic light reactions, a response consistent with the reported disruption of photosynthetic electron transport by atrazine. As soon as soil atrazine applications ceased, photosynthetic recovery of the atrazine-treated plants was indicated. We conclude that blue grama photosynthesis is initially inhibited by atrazine, and hypothesize that reported adaptive benefits of the herbicide result indirectly from stress-induced water conservation and from stimulations in photosynthesis after the inhibitory herbicidal effect dissipates.

Acknowledgements

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Denitrification Potential in a Rangeland Soil Amended with Atrazine or Hydroxyatrazine

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Guenzi, W.D., W.E. Beard, and W.G. Knight. 1991. Denitrification potential in a rangeland soil amended with atrazine or hydroxyatrazine. Pages 215-222 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

ABSTRACT

Application of low levels of atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) to short-grass prairie systems at the Central Plains Experimental Range (CPER) in north central Colorado increased herbage production and plant N concentrations. We do not know if these beneficial effects were directly related to plant responses or soil microbial N transformations. This study was designed to explore the effects of atrazine and hydroxyatrazine (2-hydroxy-4-ethylamino-6-isopropylamino-s-triazine), a degradation product of atrazine, on soil denitrification and CO_2 production. Soil collected from CPER was amended with atrazine or hydroxyatrazine and incubated under anaerobic conditions at 25°C. Gaseous N products, CO_2, and redox potentials were measured after two and six days. After two days, and with both chemicals, about half of the nitrate-N was reduced and detected as N_2O and N_2. All soil nitrate was reduced to N_2 after six days as would be expected from the low redox potentials (215-290 mV). There was no effect of atrazine or hydroxyatrazine on denitrification, except for a significant increase in N_2O concentrations with increasing atrazine concentrations after 2-days incubation. The production of CO_2 was significantly increased by atrazine after day 2, but showed no difference after day 6. The opposite was the case for hydroxyatrazine, with no differences occurring after day 2, but significant increases after day 6.

INTRODUCTION

Atrazine is applied to about 24.000 ha of grasslands annually for renovating stands of warm-season grasses by controlling invading forbs and cool-season grasses. In addition to its positive effects as a herbicide, atrazine increases herbage production, or plant N concentrations beyond that expected from weed control alone (Fedtke 1982). Atrazine can have a direct effect on plant processes, but there is less agreement regarding its effect on microbial processes in soil (Simon-Sylvestre and Fournier 1979). More specifically, if atrazine were inhibitory to the denitrification process, then NO_3^- normally lost by reduction to gaseous products would be available for plant growth. We have chosen to investigate the effect of atrazine and hydroxyatrazine (an atrazine degradation product) on the denitrification potential of a grassland soil. Existing literature contains contrasting information on the effect of atrazine on denitrification in soil and can best be described in three categories: (i) inhibition—McElhannon et al. (1984) and Mills (1984), (ii) enhancement—Cervelli and Rolston (1983), and (iii) no effect—Bollag and Henninger (1976), Grant and Payne (1982), and Yeomans and Bremner (1985). These varied results may be due to the experimental systems required to provide specific information for a given research problem. For example, approaches varied from liquid medium (soil as a source of nutrients), to salt marsh sediments used in soil slurries, to air-dried soils moistened to desired water contents. Superimposed on these systems were atrazine concentration levels ranging from 2 to 1000 mg L^{-1}. Another factor that should be considered is that atrazine degradation products may influence denitrification. Because hydroxyatrazine is the main degradation product of atrazine, we also evaluated its effect on denitrification.

MATERIALS AND METHODS

Ascalon sandy loam at a grassland site on the Central Plains Experimental Range was sampled (0-15 cm), partially dried (7.4%), passed through a 2-mm sieve, and stored at 3°C. Ascalon is of the fine loamy, mixed, mesic family of Aridic Argiustolls and was selected because it is representative of a large land area that could receive spray applications of atrazine. Soil properties were: pH 5.9; organic C, 9.83 g kg^{-1}; total N, 1.05 g kg^{-1}; sand, 62%; silt, 16%; and clay, 22%. The effects of atrazine and hydroxyatrazine on the denitrification potential were evaluated in two separate studies, separated by three weeks. Separate standard solutions of atrazine and hydroxyatrazine were made up in methanol, and acidified methanol, respectively. An aliquot of each standard was added to 1 g of soil, mixed thoroughly, equilibrated (2 hours), and dried to remove the solvent. The treated dry soil was then mixed with 49 g (air-dry basis) of untreated soil, placed in a 250-mL French square bottle, wet to field capacity (14.5%), and incubated at a constant temperature of 25°C. The experimental design included an untreated control and three atrazine or hydroxyatrazine concentration levels (0.1, 1.0, and 10 $\mu g\ g^{-1}$ soil). Each treatment was replicated three times. Each bottle was sealed with a rubber stopper which was bored to hold a platinum electrode, salt bridge (for contact with a calomel electrode), and a cut-off 1-mL syringe barrel that was attached to two four-way and one two-way stopcocks. Through these stopcocks, it was possible to evacuate the system, inject a helium atmosphere, and permit sampling for gaseous products without opening the system during incubation. Gas samples were taken after two- and six-day incubation and analyzed for CO_2, O_2, N_2, and N_2O by gas chromatography. Nitric oxide (NO) was also measured (chemiluminescence) in the six-day sample. Oxygen measurements were made to confirm that the systems remained anaerobic. Oxidation-reduction potentials were also measured after two and six days of incubation. To insure sufficient substrate for denitrification, nitrate (20 μg N g^{-1} soil as KNO_3) was added in the water used to wet the soils. After the 6-day incubation, soils (10 g) were extracted with 50 mL of 1 M KCl. Concentrations of NO_3^-, NO_2^-, and NH_4^+ were determined with an autoanalyzer (Technicon[7] 1973 a,b).

RESULTS AND DISCUSSION

The potential of this grassland soil to denitrify soil nitrate under anaerobic conditions was quite high, as all nitrate-N was converted to N_2 after six days (Table 1). There was only one case where soil treatment had a significant effect on N gas production; after a two-day incubation atrazine caused a significant ($P < 0.001$) increase in N_2O concentration (Table 1). The slightly elevated N_2O to N_2 levels with atrazine have also been reported by others (Cervelli and Rolston 1983) and implies that this chemical has a minor inhibitory effect on N_2O reduction. After day 2 and before day 6, all soil nitrate was reduced, and the resulting lower oxidation-reduction potentials facilitated rapid reduction of N_2O to N_2. Very little NO (<0.1 ηg g^{-1} soil) was detected, with no significant differences among treatments. Apparently, atrazine or hydroxyatrazine had little effect on the overall denitrification process after two and six days, even at atrazine concentrations ten-times higher than normally applied to rangeland grasses. Since soil oxidation-reduction potential ranged from 105 to 84 mV lower in the control soils of the atrazine study than those of the hydroxyatrazine study, it is difficult to compare effects of the chemicals on redox levels (Table 2). This difference in potentials was rather surprising because the only difference between the two studies was that the soil used in the hydroxyatrazine study was refrigerated three weeks longer. However, within chemicals, valid comparisons can be made. The mean oxidation-reduction potential values after two days for both the atrazine study (417 mV) and the hydroxyatrazine study (504 mV) were higher than that expected to support denitrification. However, both N_2 and N_2O were detected, so denitrification was probably occurring in microsites with a lower oxidation-reduction potential. After six days, the mean redox levels decreased to 213 mV for atrazine and 293 mV for hydroxyatrazine. At these levels, and in the absence of molecular oxygen and mineral nitrate, complete conversion of N_2O and NO to N_2 would be expected and did occur. There was no significant effect

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[7] Trade names are included in the text as a convenience to the reader and do not constitute any preferential endorsement by USDA-ARS of these products over other similar products.

of either chemical on redox potentials ($P>0.05$). except at the highest atrazine concentration (10 $\mu g\ g^{-1}$ soil) where an apparent higher redox value was obtained ($P<0.1$). More CO_2 was produced by the atrazine treated soil than the control soil after two days, but this difference was not apparent after six days (Table 3). On the other hand, soils treated with hydroxyatrazine showed no differences after two days, but did show a significant increase in CO_2 production with increasing concentrations of hydroxyatrazine after six days. For both chemicals, the generalized conclusion is that they either had no effect or a slight stimulation effect on CO_2 production. Kaiser et al. (1970) have also reported an apparent stimulation of soil microorganisms by atrazine.

Table 1. Gaseous N products released from atrazine or hydroxyatrazine treated soil during anaerobic incubation.

Chemical Conc. ($\mu g\ g^{-1}$ soil)	Gaseous N product (μg N g^{-1} soil)				
	two-days		six-days		
	N_2	N_2O	N_2	N_2O	NO
			Atrazine		
0.0	7.4	12.4	31.5	0.005	0.0006
0.1	7.5	13.0	31.4	0.003	0.0005
1.0	7.9	14.4	31.5	0.003	0.0005
10.0	7.9	14.5	31.9	0.018	0.0006
Significance(P)	>0.75	0.001	>0.75	0.25	0.75
			Hydroxyatrazine		
0.0	5.1	13.0	35.1	0.002	0.0009
0.1	5.0	13.2	34.9	0.001	0.0008
1.0	4.9	13.1	34.9	0.001	0.0009
10.0	4.6	13.4	33.9	0.001	0.0008
Significance (P)	>0.75	>0.75	>0.75	0.10	0.75

Neither atrazine nor hydroxyatrazine at any concentration level had any appreciable effect on the accumulation of ammonium or disappearance of nitrate in these anaerobic systems (Table 4). During the six-day incubation. ammonium concentration increased from 1 to 10 $\mu g\ NH_4^+$—N g^{-1} soil in all treatments, while all of the initial nitrate was reduced to N_2. No nitrite was detected before or after incubation. The studies found subtle effects of atrazine and hydroxyatrazine on both denitrification processes and anaerobic respiration. In some cases the effects were small and temporary, while in others there was clearly no effect. Although the results provided

Table 2. Oxidation-reduction potentials in atrazine or hydroxyatrazine treated soil in an anaerobic system.

Chemical Conc. ($\mu g\ g^{-1}$ soil)	Oxidation-reduction potential (mV (Eh))			
	Atrazine		Hydroxyatrazine	
	two-days	six-days	two-days	six-days
0.0	393	209	498	293
0.1	403	208	503	287
1.0	409	193	503	295
10.0	462	242	511	295
Significance (P)	0.1	0.5	>0.75	>0.75

Table 3. Carbon dioxide production from atrazine or hydroxyatrazine treated soil in an anaerobic system.

Chemical Conc. ($\mu g\ g^{-1}$ soil)	CO_2 production (μg C g^{-1} soil)			
	Atrazine		Hydroxyatrazine	
	two-days	six-days	two-days	six-days
0.0	16.2	32.6	18.4	36.4
0.1	17.0	33.4	18.8	37.5
1.0	18.8	33.9	18.7	38.3
10.0	18.8	33.9	18.9	38.8
Significance (P)	0.001	0.25	>0.75	0.005

no evidence that either chemical acts as a strong inhibitor or stimulator, both clearly have some impact on these processes under certain conditions. We believe that future research should focus on shorter studies, perhaps on the order of an hour or hours, to simulate the reducing environment that occurs in the field during and after high intensity rainfall events, which would be the dominant situation supporting denitrification in grassland soil in the Great Plains.

Table 4. Mineral nitrogen changes after an anaerobic incubation of soil amended with atrazine or hydroxyatrazine.[1]

Chemical Conc. ($\mu g\ g^{-1}$ soil)	Ammonium (μg N g^{-1} soil)		Nitrate (μg N g^{-1} soil)	
	Initial	six-day	Initial	six-day
		Atrazine		
0.0	1.1	10.3	26.1	<0.2
0.1	1.1	10.3	26.1	<0.2
1.0	1.1	11.3	26.1	<0.2
10.0	1.1	10.7	26.1	<0.2
Significance (P)	—	0.5	—	—
		Hydroxyatrazine		
0.0	0.8	10.4	32.3	0.18
0.1	0.8	10.3	32.3	0.25
1.0	0.8	10.3	32.3	0.22
10.0	0.8	10.2	32.3	0.25
Significance (P)	—	0.5	—	0.025

[1] *Nitrite concentrations, in all cases, were at or below detection limit of 0.2 μg N g^{-1} soil.*

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Residue Effects on Fallow Water Storage, Grain Sorghum Water Use, and Yield

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Steiner, J.L. 1991. Residue effects on fallow water storage, grain sorghum water use, and yield. Pages 223-230 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

INTRODUCTION

Maintaining crop residues on the soil surface often results in higher soil water content at the end of fallow for use by subsequent crops (Greb 1983, Unger 1978, Unger 1984, Unger 1986, Unger and Wiese 1979). However, it is difficult to determine in field experiments how residues affect evaporation from the soil surface (Es) and transpiration (T) during the growing season because it is difficult to measure T separately from soil Es and because of climatic variability among different years (Unger and Jones 1981, Unger et al. 1986). Simulation analyses can provide separate estimates of T and Es and allow scenarios to be tested over many climatic years.

Steiner (1989) showed that wheat residues decrease the daily potential rate of evaporation at the soil surface below residues (Eos) during the energy limited phase of evaporation:

$$Eos = Eo \cdot (1.5 - 0.20 (\ln RES)) \qquad (1)$$

where Eo is the potential evaporation at the soil surface without residues and RES is wheat residue ranging from 0 to 800 g m^{-2}. Steiner (1988), using a daily time-step water balance model modified with Eq. (1), showed reasonable estimates of soil water content after fallow, compared to measurements made in the field. A simulation was conducted to investigate the effect of wheat residues on Es, T, and growth and yield of grain sorghum assuming that residues suppress the Es portion of ET similarly to their effects during non-crop periods.

METHODS

Two simulations were conducted for the 1958-1984 climatic record of Bushland, Texas, to analyze the effect of residue amount on (1) soil water content at the end of fallow after wheat, and (2) the water balance of a sorghum crop under a range of soil water contents at planting.

CERES-Maize (Jones and Kiniry 1986) was used to simulate water storage during fallow. For each year, a fallow was initiated on July 1 (wheat harvest) with 0 mm of available soil water and terminated on the following June 1 (sorghum planting). The water balance of sorghum was simulated using SORKAM (Rosenthal et al. 1989). For each year, simulations were initiated on June 1 with 50, 100, 150, and 200 mm of initial available soil water. Plant density was 12 plants m^{-2} in 0.76 m rows. Input values for leaf number per plant was 16 and for soil profile depth was 1.7 m. The water balances of CERES and SORKAM were modified by including Eq. (1) in the calculation of the energy-limited phase of Es. Residue levels simulated were 0, 2, 4, and 8 Mg ha^{-1}. The soil in all simulations was assumed to have 192 mm of available water holding capacity and no slope. Daily climatic variables for calculation of potential ET and crop growth were maximum and minimum temperature, rainfall, solar radiation, wind-run, and average vapor pressure deficit.

Assumptions and limitations involved in this simulation include (1) the primary effect of residues on the water balance is Es suppression during the energy-limiting phase, which is extended by residues, but once a threshold cumulative Es is reached soil properties control Es; (2) residue decomposition is not considered; (3) results are applicable to non-sloping soils with high water holding capacity in the Southern Great Plains where growing season rainfall is much less than evaporative demand, and dry periods occur even in the wettest years; and (4) runoff, microclimate, and energy balance effects are not included, so, this analysis gives an incomplete estimate of residue effects on the water balance. In regions where cool spring soil temperatures are a major limitation to production, the last assumption may limit the applicability of the reported results. The simulation also assumes no-tillage management.

RESULTS AND DISCUSSION

Sorghum yields in the Southern High Plains are strongly related to soil water at planting (Jones and Hauser 1975), because stored soil water reduces plant stress during dry periods. Over 50 mm of additional water would be stored in the soil at planting with 8 Mg ha^{-1} of wheat residue, compared to no residue, at the 50% probability level (Fig. 1). The probability of having less than 100 mm of water stored in the soil at planting is 57, 47, 41, and 23% with 0, 2, 4, and 8 Mg ha^{-1} of wheat residues on the surface during fallow, respectively. With such a low water reserve, the risk of low or zero yield is high. At least 150 mm of water is stored at planting with 12, 21, 22, and 42% probability with 0, 2, 4, and 8 Mg ha^{-1} of wheat residues during fallow, respectively. This level of soil water should produce reasonable yield in this region, even in unfavorable rainfall seasons. In very good years, dryland wheat crops produce only 5 to 6 Mg ha^{-1} of residue, and levels of 4 Mg ha^{-1} or less are common. Only irrigated wheat produces the highest residue levels which were used in this simulation.

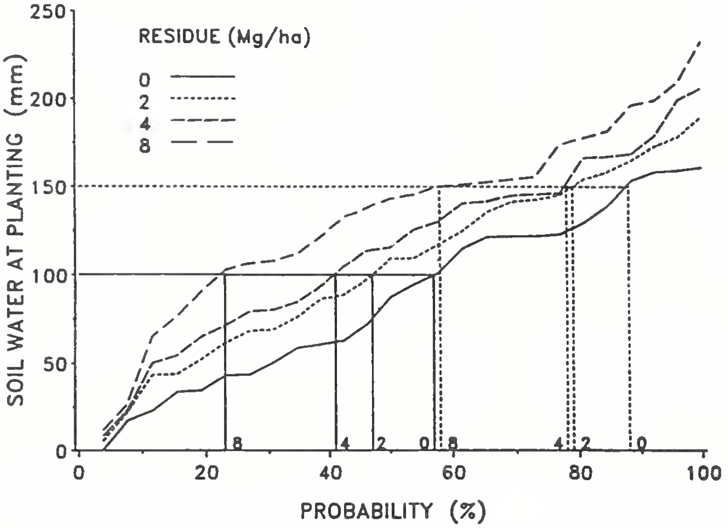

Figure 1. Simulated probability distribution of soil water content at planting with different wheat residue levels during the fallow period. (CERES simulation, 0 mm soil water at the beginning of fallow, Bushland, Texas, 1958-1984)

Residue effects on the growing season water balance of sorghum depend on soil water at planting; SORKAM runs with 50 and 100 mm initial soil water were pooled as low soil water and with 150 and 200 mm of initial soil water were pooled as high soil water. Table 1 shows that residues reduced Es and increased T. With low initial soil water, mean T was increased by 75 mm with 8 Mg ha^{-1} compared to no residue. With high initial soil water, mean T was increased 60 mm with the highest residue level. Even with only 2 Mg ha^{-1} of residues, T was increased by about 30 mm compared to a no-residue crop.

Increased T resulted in proportionately greater grain and dry matter yields with increased residue level (Table 2). Simulated mean grain yields with 8 Mg ha^{-1} of residue were increased by 1.6 and 1.1 Mg ha^{-1} compared to crops with no surface residues, under low and high soil water scenarios. With 2 to 4 Mg ha^{-1} of wheat residues, which is more realistic for dryland conditions, mean yields were increased by 0.5 to 0.9 Mg ha^{-1}, compared to no-residue crops. Water use efficiencies based on seasonal ET were greatly increased by residues, because T represented a greater proportion of seasonal ET.

Table 1. Simulated mean transpiration (T) of sorghum, evaporation from the soil (Es), total evapotranspiration (ET), and the ratio of T:ET as a function of surface crop residues under low and high initial soil water scenarios. Bushland, Texas, 1958-1984.

Residue Treatments (Mg ha^{-1})	Water Balance Component (mm) T	Es	ET	T:ET
	Low Soil Water[1]			
0	166	167	334	0.48
2	199	119	318	0.60
4	215	94	309	0.68
8	241	56	298	0.79
	High Soil Water[1]			
0	242	138	380	0.63
2	271	96	368	0.73
4	284	78	362	0.78
8	302	49	351	0.86

[1] *Low and high soil water are $\leq$ 100 mm and $\geq$ 150 mm, respectively, available soil water at planting of sorghum.*

With low soil water, higher residues increased maximum leaf area index (LAI), and therefore potential productivity of the crop (Table 3). Higher residues also reduced the number of days of crop water stress, particularly during the period from growing point differentiation to anthesis, when the plant is producing leaf area. With high soil water, residue levels did not affect peak LAI, but higher residue levels reduced water stress during the late growing season.

The simulated probability distribution of sorghum yield as a function of residues on the surface during the growing season (Fig. 2) shows that residues increased grain yield under all water conditions. High residue levels (4 or 8 Mg ha^{-1}) increased yields by 50% or more, compared to no residues throughout much of the yield probability curve. Even the low residue level (2 Mg ha^{-1}) increased yields by about 0.5 Mg ha^{-1} across a wide range of yields, which is a substantial increase for dryland sorghum.

SUMMARY

Simulation analysis predicted that maintaining residues on the surface results in more water stored during fallow compared to no residues. The simulation indicated about 50 mm of additional water was stored with high residue levels compared to bare soil. This is consistent with field results from Bushland (Unger 1978, Unger 1984, Unger and Wiese 1979). With high soil water at planting, a reasonable sorghum yield was simulated, even in the poor rainfall seasons, which is consistent with field results of Jones and Hauser (1975).

Table 2. Simulated mean sorghum grain yield (Y), above ground dry matter (DM), and water use efficiencies based on transpiration (T) or evapotranspiration (ET) as a function of surface crop residues under low and high initial soil water scenarios. Bushland, Texas. 1958-1984.

Residue Treatments (Mg ha^{-1})	Yields (Mg ha^{-1})		Water-Use Efficiencies (kg m^{-3})			
	Y	DM	Y:ET	Y:T	DM:ET	DM:T
	Low Soil Water[1]					
0	2.7	6.6	0.7	1.4	1.9	3.8
2	3.4	7.9	1.0	1.6	2.4	3.9
4	3.8	8.7	1.2	1.7	2.7	4.0
8	4.3	9.8	1.4	1.7	3.2	4.0
	High Soil Water[1]					
0	4.0	9.3	1.0	1.6	2.4	3.8
2	4.5	10.3	1.2	1.6	2.8	3.8
4	4.8	10.8	1.3	1.7	2.9	3.8
8	5.1	11.5	1.4	1.7	3.2	3.8

[1] *Low and high soil water are $\leq$ 100 mm and $\geq$ 150 mm, respectively, available soil water at planting of sorghum.*

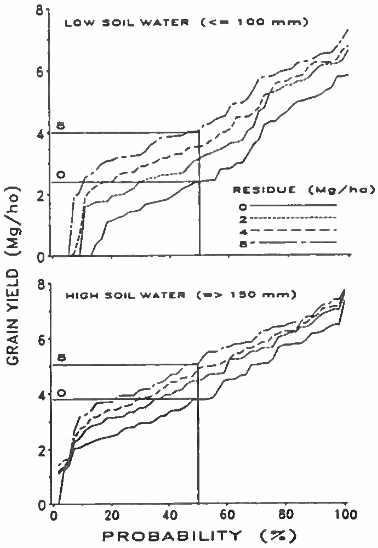

Figure 2. Simulated probability distribution of sorghum grain yield with different wheat residue levels during the growing season with low or high initial soil water. (SORKAM simulation, Bushland, Texas, 1958-1984).

Surface residues substantially reduced growing season Es, increased T, reduced plant stress, and increased yield in the simulations which assumed reduction of energy-limited Es was the primary effect of residues. Crops with little or no residue depend on high initial soil water to reduce the risk of yield failure. This analysis considered the case of a high water holding capacity soil with no runoff, no change in residue rate over time, no tillage, no significant effects of residues on microclimate or the energy balance, and no other yield limiting factors such as weeds, diseases, hail, poor stands, etc.

Residue maintenance provides a practical method to improve productivity of dryland systems by reducing Es to increase the water available to crops. It is difficult to achieve high residue levels in regions where yields are low or where residues have other economic uses, but this simulation indicates even the low residue level of 2 Mg ha^{-1} can increase sorghum water use by about 30 mm and grain yield by 0.5 Mg ha^{-1} or more. Residues in no-tillage fields have been observed to persist over 2 years in the Southern and Central Great Plains of the U.S. Finding ways to maximize crop water use by conserving residues provides a great challenge to agriculturists of the future.

Table 3. Simulated mean peak sorghum leaf area index (LAI) and days of water stress during various growth periods as affected by surface crop residues under low and high initial soil water scenarios. Bushland, Texas. 1958-1984.

Residue Treatments (Mg ha^{-1}	LAI	Days of Water Stress[2]		
		P-GPD	GPD-Anth	Anth-Mat
	Low Soil Water[1]			
0	2.5	0.2	35.3	28.4
2	2.7	0.1	27.2	28.0
4	2.8	0.0	23.4	26.6
8	2.9	0.0	19.8	25.6
	High Soil Water[1]			
0	3.3	0.0	9.0	28.1
2	3.3	0.0	7.0	26.9
4	3.3	0.0	6.4	26.0
8	3.3	0.0	5.0	24.8

[1] *Low and high soil water are $\leq$ 100 mm and $\geq$ 150 mm, respectively, available soil water at planting of sorghum.*

[2] *Predicted T reduced below potential because of inadequate soil water during three growth periods:*

- *Planting to growing point differentiation (P-GPD).*
- *Growing point differentiation to anthesis (GPD-Anth).*
- *Anthesis to physiological maturity (Anth-Mat).*

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Tillage as a Tool to Reduce Corn Rootworm Yield Loss in Maize

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ABSTRACT

Northern and western corn rootworms (*Diabrotica* spp.) are major insect pests in maize. This study was conducted to investigate the effect of conservation tillage practice and soil moisture on rootworm damage and yield loss in plants infested with known populations of western corn rootworms. The effects of soil moisture (irrigated or dryland), tillage practice (ridge tillage or spring disk tillage), and rootworm infestation (0, 1650, 3300, or 6600 eggs per meter of row) upon root damage ratings, nodal root volumes and grain yield were evaluated. Root damage ratings increased under both tillage treatments as the level of rootworm infestation increased. In the absence of irrigation, nodal root volumes and grain yield were reduced by rootworms under both tillage treatments. In irrigated plots, root volumes were larger in plants from both tillage treatments under rootworm infestation. Grain yield was reduced by rootworms in the ridge tillage plots, but was greater in

the spring disk plots infested with 1650 rootworms per meter. Grain yield, in general, was higher in ridge tillage plots than in spring disk tillage plots within comparable levels of soil moisture and rootworm infestation. These results suggest that ridge tillage may be a suitable tool for use in sustainable agriculture systems which would help ameliorate yield loss caused by rootworm infestation. Results from additional growing seasons need to be collected and evaluated in order to substantiate this suggestion.

INTRODUCTION

Northern and western corn rootworms (*Diabrotica* spp.) are major insect pests in maize. Rootworm larvae feed upon plant roots, causing plant stress, lodging and yield reduction. Crop rotation, an ideal control strategy for western corn rootworms, is less effective in controlling northern corn rootworm populations. This is because certain populations of northern corn rootworms have extended diapause which permits eggs to overwinter more than one year (Krysan et al. 1986). Current knowledge of corn rootworm/maize relationships is insufficient for rational management of these pest populations in present crop production systems and is almost nonexistent for evolving sustainable crop production systems. Thus, decision-making in sustainable agricultural production systems, whether it be for cropping sequence, planting time, tillage methods or pest control, becomes complex and must span several growing seasons. It is imperative that pest control methods become carefully integrated into sustainable agricultural production systems (see Naranjo 1989, this proceedings).

Additional information is required in order to understand the response of maize plants and corn rootworms to crop production practices used in sustainable systems. As a first step, an experiment was designed to determine the influence of conservation tillage practices and soil moisture on rootworm damage and yield loss in plants infested with known populations of western corn rootworms.

MATERIALS AND METHODS

Experimental Design

Experiments were conducted at the James River Valley Experiment Station near Redfield, South Dakota. A split-split plot experimental design was used with treatments consisting of dryland ridge till, irrigated ridge till, dryland spring disk till and irrigated spring disc till. Irrigation was the main plots, tillage was subplots and infestation was sub-subplots. Ridge till consisted of ridges 12-cm high that were formed at cultivation. All plots were placed in an area that had been continuously ridge tilled for a period of four years. The data were analyzed with ANOVA using a complete factorial with replications within plots. Fisher's protected LSD was used for mean separation.

Plots were planted with Pioneer Hybrid 3732 at a rate 67,000 kernels ha^{-1} on May 1, 1988. No soil was cleared from the ridge in the ridge tilled plots. Six replicates within each treatment were artificially infested (Sutter and Branson 1980) with western corn rootworm eggs at rates of 1650, 3300, or 6600 eggs m^{-1} of row. At the time of adult rootworm emergence from the soil, 5 root systems from each replicate were dug and rated for feeding damage (Hills and Peters 1971). On July 22, approximately three weeks after adult beetle emergence, additional root systems (five for each replicate) were dug and root volumes measured. Soil was loosened in a radius of 25 cm from the base of the plant to a depth of 30 cm allowing the root system to be removed from the ground. Excess soil was carefully removed before washing the roots. Nodes of roots were removed and their volumes measured by water displacement in graduated cylinders. Total root volumes of nodes 4 and above were determined for each plant. Ears from ten-consecutive plants in each replicate were harvested after the first killing frost. The grain was dried to 15.5% moisture and yield was determined.

Fertilization

Preseason soil tests indicated the presence of 44 kg of nitrate N, 46 kg of Bray P and 359 kg of available K ha^{-1} in the top 61 cm of soil. Twenty-seven kg of liquid 10-34-0 ha^{-1} were placed with the seed at planting and another 27 kg ha^{-1} of the same product was surface dribbled in a single band over each row. In addition, 27 kg of actual N was applied ha^{-1} in the form of liquid urea-ammonium nitrate (28-0-0) dribbled over the row at planting. Plots were cultivated twice. Irrigated plots were watered with a lateral move irrigation system and low-pressure sprinklers. Two and one half cm of water was applied each time soil matric potential at a soil depth of 46 cm fell below -0.035 MPa.

RESULTS AND DISCUSSION

Location of this study is characterized as dryland. The total precipitation received in 1988 was about 30 cm. The high density of plants used in this study, coupled with the low natural precipitation and the above normal temperatures recorded during the growing season, placed the plants grown in the absence of irrigation under drought stress.

The most sensitive measure of root damage caused by corn rootworms is achieved through the use of root damage ratings (Branson et al. 1980). This method of rating roots, however, relies solely on the number of roots damaged or removed by the insect. Important aspects of the root system are neglected by these root damage ratings, namely the amount of roots in the root system that are not damaged and the proliferation of lateral roots in moderately damaged root systems (Riedell 1989). Consequently, root damage ratings and root volumes, as well as yield, were measured in this study in an effort to accurately determine the influence of tillage and irrigation on rootworm damage and plant response.

Root damage ratings under both tillage treatments generally increased as the level of corn rootworm egg infestation increased (Table 1). In spring disk tillage the root damage ratings tended to be greater in the dryland than in the irrigated plots. The opposite was true for ridge tillage. An explanation for these results may be related to the soil moisture levels under the two tillage treatments. The soil which forms the ridges in ridge tillage tends to dry out faster after irrigation than the soil in spring disk. Excess precipitation during egg hatch is detrimental to larval establishment on corn roots in a conventional tillage system (Sutter and Gustin 1989). Therefore, soil moisture in the irrigated spring disk plots may have inhibited larval establishment which in turn reduced root damage ratings in plants grown under this treatment.

Table 1. Influence of tillage, irrigation and rootworm infestation on root damage ratings, nodal root volumes and grain yield.

Irrigation	Infestation Level (eggs m^{-1})	Root-Damage Rating (1-6 Scale)[1]	Nodal Root Volume (ml)	Grain Yield (g $plant^{-1}$)
		Spring disk		
(-)	0	2.17 a[2]	14 b	63.9 c
	1650	3.10 b	16 a	40.5 bc
	3300	4.13 c	5 b	27.1 a
	6600	4.55 c	4 b	51.6 bc
(+)	0	1.57 a	12 a	116.5 a
	1650	3.06 b	24 b	152.9 b
	3300	3.70 c	23 b	124.5 a
	6600	3.53 bc	23 b	119.9 a
		Ridge		
(-)	0	1.33 a	27 a	83.2 b
	1650	3.30 b	19 ab	62.3 ab
	3300	4.53 c	17 b	49.8 a
	6600	4.36 c	7 c	41.8 a
(+)	0	1.63 a	47 a	195.1 b
	1650	3.47 b	102 c	159.4 a
	3300	4.20 c	57 b	173.7 ab
	6600	5.00 c	50 ab	156.3 a
LSD[2]		0.49	8	21.4

[1] *Root damage rating scale: 1 = no damage, 6 = three or more nodes destroyed.*
[2] *Fishers Protected Least Significant Difference (P=0.05).*

Root volumes of Nodes 4 and above were also affected by tillage and irrigation. In the absence of rootworm infestations, plants grown under ridge tillage tended to produce larger nodal root volumes than plants grown under spring disk tillage (Table 1). Plants from irrigated ridge tillage produced larger nodal root volumes than plants under ridge tillage without irrigation. The influence of tillage and irrigation on root morphology has been discussed elsewhere (Newell and Wilhelm 1987) and will not be discussed further here.

Tillage and irrigation also played major roles in determining how plants responded to the challenge of rootworm damage. In the absence of irrigation, nodal root volumes were reduced by rootworm infestation under both tillage regimes (Table 1). In irrigated plots, however, rootworm infestation caused plants to produce nodal root volumes that were larger than uninfested plants. This increased nodal root volume under rootworm infestation is particularly striking in the irrigated ridge till plots infested with 1650 eggs per row meter. These results suggest that adequate soil moisture provided by irrigation and the lower density of rootworm larvae allowed plants to regenerate roots in response to rootworm infestation.

Grain yield was also affected by tillage and irrigation treatments. In general, yield was higher under ridge till than under spring disk (Table 1). Yield was also increased within these tillage treatments by irrigation. These irrigation effects were expected because of the dryland nature of the research location.

Rootworm infestation reduced grain yield under both spring disk and ridge till in the absence of irrigation (Table 1). Plants grown under irrigated ridge till with rootworm infestation had reduced yield, but the magnitude of yield loss recorded in this treatment was less than the magnitude of yield loss seen in the absence of irrigation. We observed a yield increase in spring disk plots infested with 1650 eggs m^{-1} maintained under irrigation. Irrigated ridge tillage produced greater yield at 3300 and 6600 eggs m^{-1} infestation levels than irrigated spring disk.

The agronomic and physiological reasons for these varied yield responses to corn rootworm infestation under different tillage and irrigation treatments studied in this report are not fully known at this time. However, one possible explanation of the increased yield in infested 1650 eggs m^{-1} row plants grown under irrigated spring disk tillage relates to the fertilizer placement. We placed nitrogen and phosphorus fertilizer in a band over each row. Rootworm infestation stimulated lateral root proliferation (determined by increased root volume) in the nodes of roots that were growing in the region of soil where fertilizer was applied. Consequently, absorption of these nutrients could have taken place with greater efficiency in plants that were infested with relatively low densities of rootworms. Additional data are needed to further investigate these aspects of plant-insect-tillage interactions.

SUMMARY

The results presented here for one year of an on-going study indicate that ridge tillage, a form of conservation tillage which reduces soil erosion and conserves soil moisture, produces plants that yield as well or better under the stress of rootworm infestation than plants grown in a more conventional tillage system. Consequently, ridge tillage may be a suitable tool for use in sustainable agricultural systems in humid environments which would help ameliorate yield loss caused by rootworm infestation. Results from additional growing seasons need to be collected and evaluated in order to substantiate this suggestion.

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Impacts of Agricultural Practices on Nitrate Concentrations of Ground Water in the Southern Plains

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Naney, J.W., S.J. Smith, D.C. Kent, W.A. Berg, and B.B. Webb. 1991. Impacts of agricultural practices on nitrate concentrations of ground water in the Southern Plains. Pages 237-244 *in:* J.D. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole (eds.), *Sustainable Agriculture for the Great Plains, Symposium Proceedings.* USDA, ARS, ARS-89, 255 pp.

ABSTRACT

The potential for ground-water contamination by water soluble chemicals has increased the need for knowledge about chemical transport by subsurface water. Fertilizers and other agricultural chemicals are used in moderate to deep sandy and loamy soil environments which are planted to wheat, cotton, and grain sorghum throughout much of the Southern Plains of the U.S. Tillages ranging from no-till to conventional till, crop type, and depth to water table are factors under investigation to determine the impacts of agricultural practices on ground-water quality. Water quality analyses for fifty-four wells representing thirty-seven watershed are presented for periods of 3 to 9 years. Ground water beneath watersheds planted primarily to minimum tillage wheat on an annual basis and under fertilized grasses in shallow (<4 m) water-table areas has shown a trend of increasing nitrate-N when

excess rainfall occurs. Increases in NO_3—N have resulted under minimum tillage wheat watersheds at Woodward, El Reno, and Perkins, Oklahoma. In two watersheds at El Reno, similar except for tillage practices, nitrate-N concentrations increased over time under minimum tillage and decreased or increased only slightly under conventional tillage for the same six-year period.

INTRODUCTION

In recent years the use of agricultural chemicals and the greater awareness of the potential for ground water contamination by water soluble chemicals has increased the need for information on chemical transport by subsurface water movement. Throughout the Southern Plains of the U.S., fertilizers, such as nitrogen (N) and phosphorus (P), are added to agricultural soil, often annually, to improve soil fertility. Factors such as cropping and tillage must be considered in accounting for the fate of these chemicals and the amounts and timing of their transport to the water table.

While the presence of nitrate-N (NO_3—N) in ground water supplies has been related to source areas such as farmsteads (Johnson 1966), an increase in the amounts of commercial N fertilizers applied to agricultural cropland and pastures has also occurred (Hargett and Berry 1985). Thus the potential for N-leaching to the water table is enhanced under climatic conditions common to much of the Southern Plains which includes parts of Oklahoma and north central Texas where the climate is sub-humid with late spring and summer thunderstorm activity and early fall precipitation. Leaching occurs even with dryland farming practices such as those used in this study. Fertilizers and other agricultural chemicals are used in most soils including moderate to deep sandy and loamy soils which are planted to wheat, cotton, and grain sorghum throughout much of the Southern Plains of the U. S. The impacts of agricultural practices on the NO_3—N concentration of ground water was investigated over the last 9 years, for tillages ranging from no-till (crop residue $\geq$ 30% constitutes reduced tillage and includes no-till, low-till, and min-till systems) to conventional till, crop type, and depth to water table.

STUDY AREA AND METHODOLOGY

This study reports the chemical composition of ground water from fifty-four wells in thirty-seven small watersheds which range in size from 1 to 14 acres and which were selected as representative of the major land resource areas in predominantly agricultural lands in Oklahoma. General descriptions of the watersheds have been published previously (Naney et al. 1988, Sharpley et al. 1987), which includes a range of soils (Alfisols, Inceptisols, and Mollisols), geologic formations (Quaternary terrace and Entisols deposited over Permian red beds of sandstone, shale, and evaporties), slopes (1 to 9%), grasses (native, tall, and mid-grasses), crops (wheat, sorghum, peanuts, cotton, and orchard/grass), tillages (conventional and low-till), fertilizer application rates (N, 0-135; P, 0-34; K, 0-11 kg ha^{-1} yr^{-1}), and lengths of study (3 to 9 years).

Monitor wells were completed to depths between 3 and 40 m and were cased with the upper 2 to 6 m sealed with cement or bentonite slurry to prevent direct surface inflow. Geological, soil, and well completion data are discussed earlier (Naney et al. 1988). Both geology and soil are heterogeneous in all watersheds within the study sites. Wells were bailed or pumped one day prior to sampling to assure samples represented water from the aquifer. All well samples were refrigerated at approximately 4°C until chemical analysis was completed. Chemical analysis for NO_3—N, was made using standard methods described in the Federal Water Manual (U. S. Department of Interior 1971). Publications by the U.S. Environmental Protection Agency (1973, 1976) were used as guides for water quality standards.

RESULTS AND DISCUSSION

Nitrate-N concentrations of wells associated with the various land-use practices are given in Table 1. For reference purposes, NO_3—N concentration within 10 and 100 mg l^{-1} were considered acceptable for human and livestock consumption purposes, respectively. The results presented here indicate that NO_3—N concentrations of all the wells were within livestock consumption limits and on the average, most were within human consumption limits. However, there were some noteworthy exceptions.

These exceptions occurred on minimum-till wheat at El Reno, Perkins, and Woodward, and conventional-till wheat and certain improved grasses at Perkins and Woodward. Both the high single concentrations (92.5 mg l^{-1}) and the highest average concentrations (43.6 mg l^{-1}) were observed on minimum-till wheat at Perkins. Nitrate-N concentrations tended to increase in a northeasterly direction across Oklahoma (Fig. 1). In general, the high NO_3—N concentrations were observed in wells on shallow water table (<7 m) sandy soils that had received N fertilizer at annual rates of 7-135 kg ha^{-1} for several consecutive years. Overall, the exceptions clearly point out the potential for NO_3—N contamination of ground water associated with wheat and improved grass production in Oklahoma.

Due to the increased adoption of minimum-tillage, particular attention should also be given to potential NO_3—N contamination of ground water. Minimum tillage provides a wetter, cooler soil environment that may enhance nitrate leaching potentials (Dick et al. 1986). Practices that may reduce nitrate leaching potentials on susceptible soils include applying proper N rates, i.e. realistic yield goals, splitting the N application, and better timing of the applications.

Watersheds in similar topographic, climatological, and geological settings, but under distinctly different management schemes were sampled at the El Reno and Woodward locations (Fig. 2). In each case, a monitor well near the top of the watershed (upslope), midway downslope (midslope) and near the bottom of the watershed slope (downslope) was used to monitor changes in ground-water quality over a period of six years (1983 through 1988).

Results of ground-water analyses from two watersheds at Woodward, WW-4 in minimum-tillage wheat and WW-2 in grass, with similar slope, soil, geology, and climate, are presented graphically for the years 1983 through 1988 in Figures 2a and 2b, respectively. It is notable from Figures 2a and 2b that, whereas some increase in NO_3—N (2-4 mg l^{-1}) has occurred in water from the upslope and midslope wells on WW-2, (native range), NO_3—N has increased nearly 10 mg l^{-1} in the midslope well of WW-4 (minimum-tillage wheat) since September 1984. The heterogeneous nature of both soils and geology within each watershed apparently creates differential transport of chemicals to individual wells.

Watersheds at El Reno with similar slope, soil, geology and climate, and maintained in minimum-tillage wheat, conventional-tillage wheat, grain sorghum/wheat, and fertilized grass were observed and sampled. The changes in NO_3—N are presented graphically for each of the management practices in Figure 2c, 2d, and 2e, respectively. The increased concentrations of NO_3—N both in a downslope direction and over time is evident for the minimum-tillage wheat watershed (Fig. 2c) and is a rapidly increasing trend compared to conventential-tilled wheat (Fig. 2d) or grass (Fig. 2e) watersheds.

SUMMARY AND CONCLUSIONS

The results of ground water monitoring at five diverse sites in the major agricultural areas in Oklahoma indicate some impacts of land use on ground-water quality. Nitrate-N concentrations above the U.S. EPA standards for humans at the Perkins, El Reno and Woodward sites indicate the need for continued monitoring to evaluate long term changes in ground water quality. Additionally, some changes in agricultural practices such as rates and timing of fertilizer-N applications, or tillage modifications in certain geological and climatological areas may be necessary, if increases in NO_3—N in ground water persist under current management schemes.

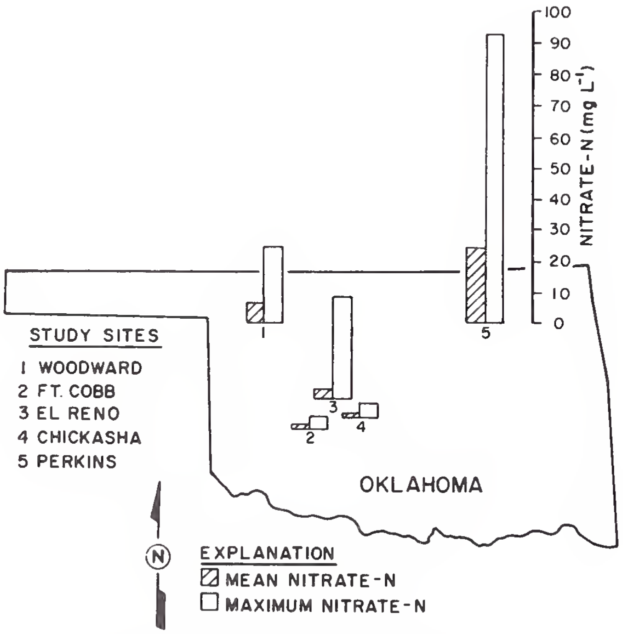

Figure 1. Mean and maximum nitrate-N concentrations in ground-water wells on watersheds in Oklahoma.

Table 1. Nitrate in ground waters beneath watersheds in Oklahoma affected by agricultural practices common to the Southern Plains.

Watersheds in Oklahoma	Period	Practice	Wells	Samples	NO_3—N (mg l^{-1})	
					Range	x±sd
		Grasses and Legumes				
Woodward	1980-88	Eastern Gama Grass	6	112	0.0—14.0	2.3±2.9
Woodward	1980-88	Love Grass	2	36	2.6—14.8	8.2±2.6
Woodward	1981-85	Alfalfa	1	12	0.8—08.3	6.6±2.7
Woodward	1981-88	Bermuda Grass	4	72	0.1—11.9	4.6±5.7
Woodward	1982-88	Old World Bluestem	2	28	11.1—24.1	17.9±2.4
Woodward	1983-88	Native Grass	3	36	1.4—09.1	3.1±2.2
Ft. Cobb	1983-88	Peanut	1	14	0.0—09.0	4.0±2.5
El Reno	1980-88	Native Grass	7	54	0.0—11.9	1.6±1.1
Chickasha	1979-82	Native Grass	2	9	0.1—00.9	0.5±0.4
Perkins	1986-88	Orchard/Grass	1	8	9.3—36.8	18.7±5.2
		Conventional Tillage				
Woodward	1981-87	Wheat	2	36	2.2—12.0	5.6±3.1
Ft. Cobb	1983-88	Grain Sorghum	1	16	0.7—06.0	2.7±0.5
El Reno	1983-88	Grain Sorghum/Wheat	3	29	0.2—08.8	1.4±0.9
Chickasha	1979-82	Wheat	5	9	0.1—04.1	1.2±1.4
Perkins	1986-88	Wheat	3	23	6.7—43.6	28.9±11.4
Perkins	1986-88	Cotton	1	8	4.5—08.3	6.0±1.7
		Minimum Tillage				
Woodward	1983-87	Wheat[1]	3	36	0.0—11.2	1.8±3.2
El Reno	1983-88	Wheat	3	39	1.5—32.1	11.5±4.9
Perkins	1983-88	Wheat	4	33	21.0—92.5	43.6±18.4

[1] *Watershed converted to Native grass April 1987.*

Source: Naney et al., (1988).

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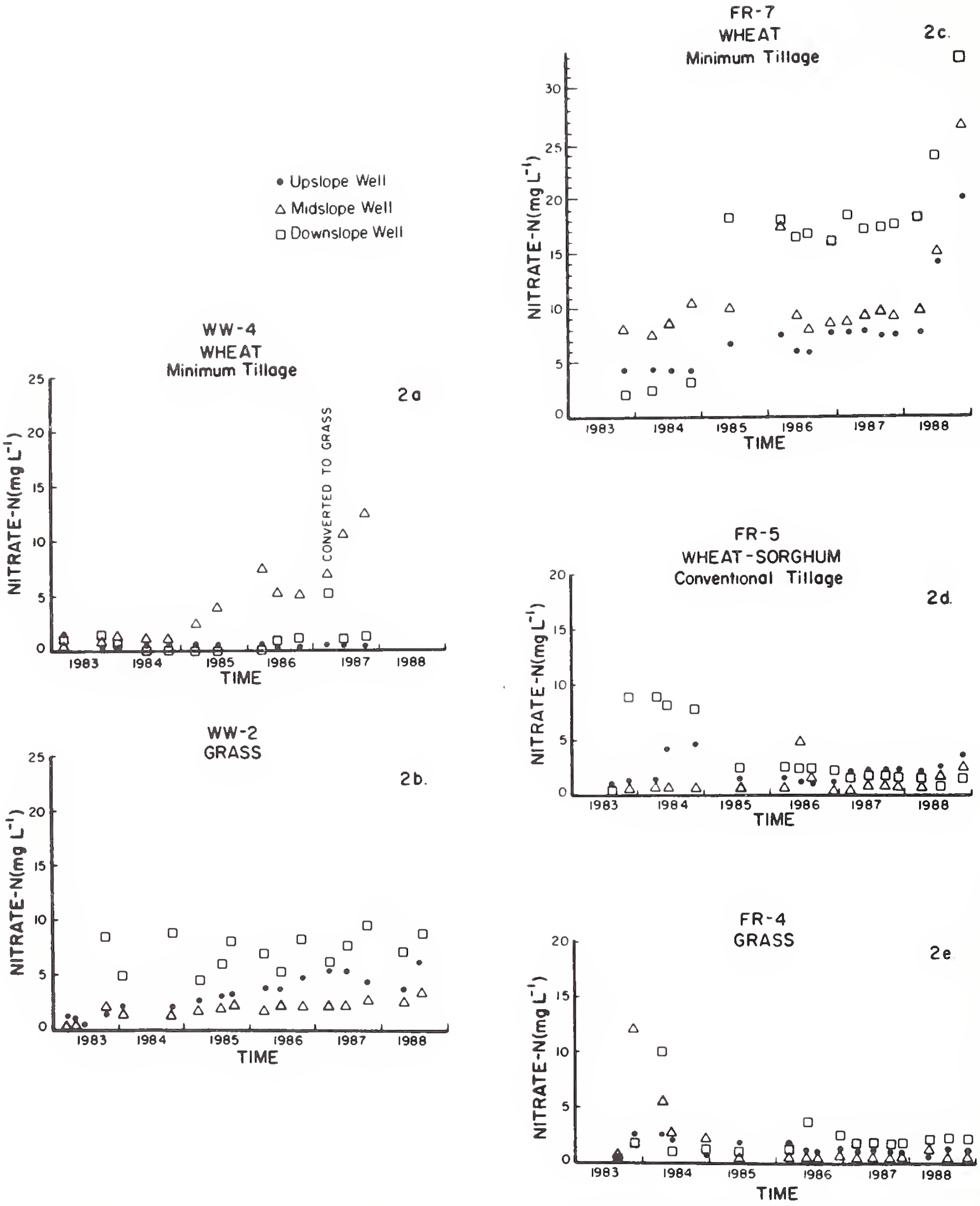

Figure 2. Nitrate-N concentrations under a) minimum tillage wheat and b) grass cover at Woodward, Oklahoma, and c) minimum tillage wheat, d) conventional tillage grain-sorghum/wheat, and e) fertilized grass at El Reno, Oklahoma.

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Wind in the Great Plains: Speed and Direction Distributions by Month

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ABSTRACT

Wind erosion and drought threaten the sustainability of agriculture in the Great Plains. Strong winds constrain crop production by blowing snow off the fields, increasing potential evaporation, and eroding soil. To better cope with the wind in the Great Plains, we have developed a detailed data base. We used Wind Energy Resource Information System (WERIS) data obtained from the National Climatic Data Center for 208 locations in the Great Plains. We analyzed the WERIS data to determine scale and shape parameters of the Weibull distribution for each of the 16 cardinal directions for each month at each location. We also summarized wind direction distributions by month for each location. The wind direction summaries give the probability of wind from each of the 16-cardinal directions plus calm periods. Additionally, the monthly average ratio of daily maximum to minimum hourly wind speed. hour of maximum wind speed. and air density are given. These data indicate not only wind speed and wind direction probabilities by month but also provide additional information for calculating wind power and diurnal and hourly wind speed variations.

INTRODUCTION

The wind is of interest to many people. Wind energy developers, hydrologists, meteorologists, climatologists, farmers, ranchers, sportsmen, environmentalists, conservationists, agricultural pest managers, housewives, and others all have reasons to know about the wind.

This need to know about the wind has prompted several studies, particularly by those interested in wind as a source of energy (Hagen et al. 1980, Reed 1975, Elliot et al. 1987) and those concerned with erosion of soil by wind (Lyles 1976, Lyles 1983, Zingg 1949, Skidmore 1965, Skidmore 1987).

Skidmore (1965) computed wind erosion force vectors from frequency of occurrence of direction by wind speed groups. The wind erosion force vectors were used to compute monthly magnitudes of wind erosion forces, prevailing wind erosion direction, and preponderance of wind erosion forces in the prevailing wind erosion direction. These factors, which indicate, respectively, potential need for wind erosion protection, proper orientation of erosion control measures, and relative merits of proper orientation of the control methods, were furnished by month for 212-locations throughout the United States (Skidmore and Woodruff 1968). The resulting handbook since has been used for conservation planning and wind erosion prediction. The prevailing wind erosion direction and preponderance data are included in the recent SCS National Agronomy Manual (1988). In that manual, magnitude of wind erosion forces was presented in an erosive wind energy distribution format, as developed by Bondy et al. (1980) and Lyles (1983).

Although these wind analyses were essential for conservation planning and wind erosion prediction with the wind erosion equation of Woodruff and Siddoway (1965), they are not adequate for the evolving wind erosion technology (Hagen 1988). The purpose of this research was to develop a wind data base suitable for use in the stochastic approaches in the current wind erosion modelling effort. The same data should benefit other scientists and resource managers needing wind data.

METHODS

We obtained the Wind Energy Resource Information System (WERIS) data base from the National Climatic Data Center on digital 9-track tape in ASCII format. This data base contains information for more than 900-locations in the U.S. and 208-locations in the Great Plains (Fig. 1). The data base was prepared by the Pacific Northwest Battelle Laboratory for the U.S. Department of Energy (Elliot et al. 1987). During 1981 and 1982, the WERIS data base was integrated into a computerized data base and transferred to the National Climatic Data Center, Ashville, North Carolina (NCC TD 9793).

Each location in the WERIS data base is identified by a unique Weather-Bureau-Army-Navy (WBAN) station number. WERIS includes data for various periods of record during 1947 through 1978 for which the anemometer height, anemometer location, and frequency of observation remained constant.

WERIS consists of 19-tables of wind statistics for each location (Table 1). Data were extracted from these tables and, in some cases, analyzed further to create a database suitable for our needs.

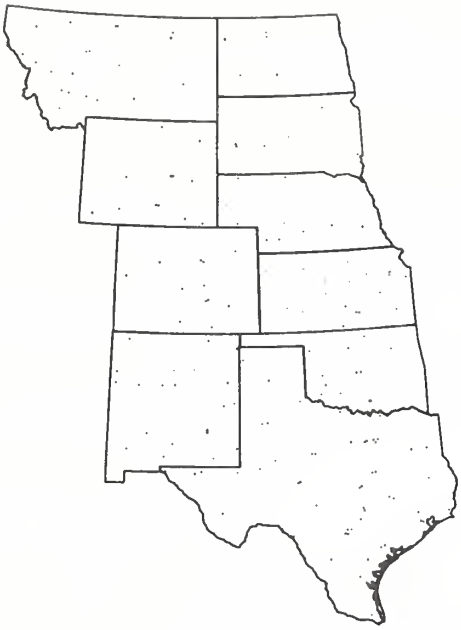

Figure 1. Locations in the Great Plains for which wind data are summarized.

From WERIS Table 5. we obtained a ratio of maximum/minimum mean hourly wind speed and hour of maximum wind speed by month. From WERIS Table 10, we obtained monthly mean air density and occurrences of blowing dust. Air density is used to calculate wind power and wind shear stress. Although we are not using occurrence of blowing dust in our current modelling effort, we thought it important to archive in our data base for future studies.

We used data from WERIS Table 12 A-L, joint wind speed/direction frequency by month (Table 2), to calculate scale and shape parameters of the Weibull distribution function for each of the 16 cardinal wind directions by month. The cumulative Weibull distribution function F(u) and the probability density function f(u) are defined by:

$$F(u) = 1 - \exp(-(u/c)^k) \qquad (1)$$

and

$$f(u) = dF(u)/du = (k/c)(u/c)^{k-1} \cdot \exp(-(u/c)^k) \qquad (2)$$

where u is wind speed, c is scale parameter (units of velocity), and k is shape parameter (dimensionless) (Weibull 1951. Apt 1976). Since anemometer heights varied from location to location, all wind speeds (Column 1, Table 2) were adjusted to a 10-m reference height according to the following:

$$u_2 = u_1(z_2/z_1)^{1/7} \qquad (3)$$

where u_1 and u_2 are wind speeds at heights z_1 and z_2, respectively, (Elliot 1979).

Table 1. Summary of statistics in the Wind Energy Resource Information System (WERIS) (Elliot et al. 1987).

Table	Description	No. of Pages
01	Hourly Mean Speed and Frequency by Month	12
02	Annual Hourly Mean Speed and Frequency	1
03	Annual hourly Speed Duration	1
04	Average Wind Speed and Wind Power (Hr, Month, Season)	1
05	Maximum and Minimum Mean Hourly Wind Speed by Month	1
06	Average Wind Speed and Power (Month, Year)	1
07	Standard Deviation of Speed and Power (Month, Year)	1
08	Wind Speed Pattern Factor (Month, Year)	1
09	Number of Observations (Month, Year)	1
10	Significant Weather Parameters and Events by Month	1
11	Monthly Wind Speed Frequency	1
12	Joint Wind Speed/Direction Frequency by Month	12
13	Annual Joint Wind Speed/Direction	1
14	Annual Joint Wind Power/Direction Frequency	1
15	Wind Speed Duration by Direction by Month	12
16	Annual Wind Speed Duration by Direction	1
17	Annual Wind Power Duration by Direction	1
18	Wind Speed Persistence above Speed Threshold	1
19	Wind Direction Constancy by Direction	1
	Total No. of Pages	52

The calm periods were eliminated, and the frequency of wind in each speed group was normalized to give a total of 1.0 for each of the 16-cardinal directions. Thus,

$$F_1(u) = ((F(u) - F_0)/(1 - F_0)) = 1 - \exp(-(u/c)^k) \qquad (4)$$

where $F_1(u)$ is the cumulative distribution with the calm periods eliminated, and F_0 is the frequency of the calm periods. The scale and shape parameters were calculated by the method of least squares applied to the cumulative distribution function, Equation (4). Equation (4) was rewritten as

$$1 - F_1(u) = \exp(-(u/c)^k). \qquad (5)$$

Then by taking the logarithm twice, this becomes

$$\ln(-\ln(1 - F_1(u))) = - k \cdot \ln(c) + k \cdot \ln(u). \qquad (6)$$

If we let $y = \ln(-\ln(1 - F_1(u)))$, $a = -k \cdot \ln(c)$, $b = k$, and $x = \ln(u)$, Equation (6) may be rewritten as

$$y = a + bx. \qquad (7)$$

$F_1(u)$ was calculated from information in tables like Table 2 for each wind speed group, to determine y and x in Equation (7). This gave the information needed to use a standard method of least squares to determine the Weibull scale and shape parameters. To recover the real distribution, one can rewrite Equation (4) as

$$F_1(u) = F_0 + (1 - F_0)\{1 - \exp(-(u/c)^k)\}. \qquad (8)$$

Wind direction distribution was summarized by month from the "total" row in Table 2 for each location.

Other pertinent data, obtained from the Wind Energy Resource Atlas of the United States (Elliot et al. 1987), included latitude, longitude, city, state, location name, WBAN number, period of record, anemometer height, and number of observations per 24-hour period.

We eliminated WERIS sites if they represented less than 5-years of data, the anemometer height was not known, or fewer than twelve observations were taken per day. This process of elimination reduced the number of Great Plains sites from 208 (WERIS) to 161 (Appendix A). Where more than one observation site/period remains in a metropolis area, one may pick the site with the best combination of the following:

- maximum number of hours per day observations were taken,
- longest period of record,
- one-hourly versus three-hourly observations, and
- best location of anemometer (ground mast > beacon tower > roof top > unknown location).

RESULTS

Tables 3, 4, 5, and 6 give examples of wind information we compiled for 161 Great Plains locations (Appendix A). The data are stored in computer files in ASCII format and require approximately 600 kilobytes.

The scale and shape parameters (Tables 4 and 5) are used in Equations (1) and (2) to define the wind speed probability distribution functions and have much utility for describing the wind speed regime. Equation (2) can be used to calculate the probability of wind for any specified speed. The integrated form of Equation (1) can be used to calculate the probability of wind speeds being greater than, less than, or between specified values. The mean wind speed of the observation period from which the distribution parameters were calculated is very nearly 0.9 times the scale parameter (Johnson 1978).

An example of wind speed distributions with various scale and shape parameters is presented in both bar graph and xy plot in Figure 2. The bar graph was produced from original data as in Table 2. The wind speed data were corrected to an anemometer height of 10 m and normalized to 1.0 for total in each cardinal direction before plotting. The continuous curve (xy plot) was calculated from Equation (2); scale and shape parameters were obtained from Tables 4 and 5, respectively, corresponding to specified month and wind direction. Scale parameter of Figure 2a is located in Table 4, month 12, and direction 6; likewise, shape parameter of Figure 2a is located in Table 5, month 12, and direction 6. Weibull scale and shape parameters were used to calculate the wind speed distributions illustrated by Figure 3.

Table 2. Joint wind speed/direction frequency, March, Lubbock, Texas, (after Table 12c of WERIS).

	WIND DIRECTION																
SPEED (m sec^{-1})	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	CALM	TOTAL
CALM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.7	1.7
1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2	.3	.1	.1	.0	.1	.1	.2	.1	.3	.1	.5	.5	.6	.4	.5	.2	.0	4.1
3	.7	.3	.5	.4	.9	.4	.6	.5	.9	.4	1.1	1.1	1.5	.8	.7	.3	.0	11.1
4	1.0	.6	.8	.4	1.1	.9	1.0	.8	1.9	.6	.8	1.2	1.6	1.2	.7	.5	.0	15.1
5	.9	.6	.8	.5	.9	.9	1.0	1.3	2.1	.9	1.2	1.2	1.6	.5	.4	.5	.0	15.4
6	.7	.7	.6	.4	.6	.5	.9	.6	1.6	1.0	1.1	1.2	.7	.6	.3	.5	.0	12.2
7	1.0	.6	.6	.4	.2	.5	.4	.5	1.6	1.0	1.4	.8	.7	.5	.3	.2	.0	10.0
8	1.0	.6	.8	.2	.5	.3	.6	.3	1.4	1.2	1.0	.6	.7	.4	.4	.2	.0	10.1
9	.8	.4	.6	.2	.3	.1	.2	.4	1.0	.8	.7	.6	.6	.4	.2	.3	.0	7.6
10	.3	.4	.2	.2	.1	.0	.1	.2	.8	.4	.2	.3	.4	.3	.1	.1	.0	4.3
11	.3	.4	.1	.1	.0	.0	.1	.1	.5	.2	.3	.3	.5	.1	.1	.1	.0	3.1
12	.2	.1	.0	.0	.0	.0	.0	.1	.0	.1	.1	.2	.4	.1	.1	.0	.0	1.6
13	.2	.1	.0	.0	.0	.0	.0	.0	.0	.8	.2	.1	.3	.2	.1	.1	.0	1.3
14	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1	.2	.1	.1	.0	.0	.7
15	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1	.0	.0	.0	.0	.0	.5
16	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1	.0	.0	.0	.0	.2
17	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.1
18	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1
19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1
20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
21-25	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Table 2. Continued.

	WIND DIRECTION																
SPEED (m sec^{-1})	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	CALM	TOTAL
26-30	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
31-35	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
36-40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
41-up	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	7.8	4.8	5.1	2.9	4.9	3.8	5.1	4.9	12.2	6.8	8.9	8.5	9.9	5.7	4.0	3.0	1.7	100.0
Avg. Speed	6.9	7.0	6.1	6.0	5.1	5.2	5.5	5.9	6.2	6.7	6.4	6.2	6.4	6.2	5.6	6.3	.0	6.1

Table 3. Ratio of maximum to minimum hourly wind speed, hour of maximum wind speed, air density, and occurrences of blowing dust, Lubbock, Texas.

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Max/Min	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.7	1.5	1.6	1.6	1.5
Hr. Max	15	12	15	15	18	18	18	15	15	15	12	15
Air Den.	1.14	1.13	1.11	1.09	1.07	1.06	1.05	1.06	1.07	1.09	1.12	1.13
Dust	43	56	122	119	41	28	3	3	1	4	25	49

Table 4. Weibull scale parameters ($m\ s^{-1}$) by month and direction. Wind speed was adjusted to a height of 10-meters, Lubbock, Texas.

Direction[1]	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	8.0	8.2	8.8	8.3	8.0	7.6	5.8	5.0	6.4	7.5	7.5	7.9
2	8.2	9.2	9.0	8.6	8.3	7.6	6.0	5.7	7.3	7.5	6.7	8.1
3	6.6	7.8	8.0	8.3	7.9	7.2	5.8	5.8	5.9	7.0	6.5	6.8
4	6.5	6.5	7.8	6.9	7.3	6.3	5.9	5.2	5.3	6.2	5.7	6.3
5	6.0	6.3	6.7	6.4	6.6	6.3	5.2	4.8	4.6	5.2	5.0	5.0
6	5.3	6.4	6.8	7.1	7.1	6.2	5.3	5.0	5.2	5.1	5.1	4.2
7	5.5	6.4	7.2	7.2	7.4	6.8	6.0	5.5	5.5	5.3	4.8	5.2
8	5.9	6.1	7.5	8.5	8.0	7.5	6.3	5.8	5.9	6.2	5.8	5.2
9	6.2	7.0	7.9	8.5	8.1	8.0	6.8	6.5	6.5	6.6	6.2	6.5
10	7.2	7.2	8.7	8.5	8.1	7.7	6.9	6.5	6.9	6.9	6.9	7.4
11	7.3	7.6	8.2	8.4	7.6	6.9	6.1	5.9	6.1	6.2	6.5	6.9
12	6.5	7.0	8.0	8.6	7.8	7.0	5.4	5.0	5.2	5.9	6.4	6.0
13	6.7	6.8	8.3	8.8	7.2	6.4	4.9	4.4	5.3	5.1	6.3	6.4
14	7.1	7.2	7.8	8.1	7.0	5.6	4.3	4.2	4.6	5.1	6.0	6.9
15	6.1	6.1	7.2	7.2	7.1	5.3	4.6	4.5	4.4	4.9	6.4	6.5
16	7.1	7.7	7.7	8.3	6.6	5.7	4.8	3.9	4.9	6.4	7.1	7.2
17	6.8	7.3	8.1	8.2	7.7	7.3	6.3	5.8	5.9	6.3	6.4	6.7

[1] *The directions are clockwise starting with 1 = north. Direction 17 is for total wind.*

Table 5. Weibull shape parameters by month and direction, Lubbock, Texas.

Direction[1]	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	2.5	2.5	2.7	2.6	2.8	2.3	2.2	2.6	2.3	2.5	2.7	2.7
2	2.8	2.4	3.2	2.9	2.8	2.7	3.2	2.3	3.1	2.8	2.7	2.6
3	2.8	3.1	3.3	2.8	2.7	2.9	2.8	3.3	3.2	3.3	3.0	3.2
4	3.9	3.4	3.0	3.5	3.0	2.6	2.8	2.9	3.2	3.1	2.7	3.2
5	3.1	3.2	3.3	2.9	3.0	3.4	3.1	3.2	3.3	3.0	3.6	2.8
6	3.4	3.6	3.9	3.3	3.6	4.4	3.7	3.9	3.3	3.5	3.6	5.1
7	3.7	3.3	3.3	3.3	3.4	3.6	3.5	3.5	3.9	4.1	3.6	5.4
8	3.2	4.1	3.3	3.5	3.3	3.5	3.8	3.7	3.5	2.9	3.0	4.5
9	2.9	3.2	3.6	3.3	3.3	3.7	3.7	3.7	3.4	3.3	3.3	3.2
10	3.1	3.5	3.7	3.7	3.2	3.5	3.9	3.6	4.0	3.2	3.5	3.2
11	3.4	3.2	2.7	3.2	3.2	3.0	3.5	3.0	3.4	3.0	3.2	3.2
12	2.5	2.6	2.5	2.4	2.5	2.9	3.4	3.6	3.0	2.7	2.6	2.6
13	2.1	2.4	2.2	2.5	2.6	2.2	3.3	3.1	3.0	2.4	2.2	2.2
14	2.1	2.2	2.3	2.5	2.4	3.6	4.1	3.5	2.6	2.4	1.8	2.0
15	2.4	2.6	2.2	2.5	2.5	3.1	3.3	2.9	2.9	2.0	2.2	2.3
16	2.2	2.6	2.7	2.3	2.8	3.3	2.6	3.5	2.5	2.1	2.4	2.4
17	2.6	2.6	2.7	2.9	3.0	3.1	3.3	3.2	3.0	2.7	2.6	2.6

[1] *The directions are clockwise starting with 1 = north. Direction 17 is for total wind.*

Figure 3 is intended to give a visual overview of wind speed distributions at a location. Each of the eight ridges in the figure is at 45 degree intervals and oriented in the direction of the wind it represents. For example, the two ridges that approach the axis at the left and right 0 are for wind speed distributions from the west and south, respectively. It is seen by comparing these ridges to their parallel wind speed scales that the westerly winds have a higher probability than southerly at high wind speeds but that southerly winds have a higher probability at medium wind speeds.

We determined the distribution of the coefficients of determination, r-squared, of the fit of the Weibull parameters to the wind speed data (direction and month) for four sites in each of the 10 Great Plains states; sample size equalled 7,680. The percentages of r-squared exceeding 0.98, 0.96, and 0.94 were 37, 67, and 82, respectively. In December, less than 2% of the wind was from ESE (Fig. 2a), whereas more than 27% was from the south in July (Fig. 2d). The corresponding r-squares were 0.90 and 0.99, respectively.

Wind direction distribution data, as in Table 6, are plotted for February and July in Figure. 4. No strongly favored direction is apparent for February, but the winds are strongly southern in July.

Table 6. Wind direction distribution (%) by month, Lubbock, Texas.

Direction[1]	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	8.2	9.7	7.8	5.5	5.3	3.1	2.3	2.9	5.9	6.3	8.8	9.0
2	5.0	4.9	4.8	3.6	3.7	2.2	1.5	2.6	4.8	5.0	4.4	4.8
3	5.0	5.9	5.1	4.1	4.1	3.2	3.9	4.2	6.3	5.3	4.8	4.7
4	3.8	4.2	2.9	4.5	4.8	4.1	3.8	4.7	4.9	4.1	3.1	3.1
5	4.0	4.3	4.9	5.3	5.9	5.0	5.9	6.7	6.3	4.3	4.4	2.2
6	3.1	3.8	3.8	4.7	6.6	6.1	5.7	6.3	5.7	3.0	3.2	1.9
7	3.3	3.8	5.1	6.5	10.5	10.4	10.0	9.7	7.5	4.2	3.4	2.1
8	2.9	3.3	4.9	4.9	8.3	9.5	11.6	14.9	13.6	9.0	5.4	3.7
9	9.8	8.7	12.2	16.4	16.4	26.8	27.4	24.1	18.6	19.7	11.7	9.4
10	6.0	5.7	6.8	6.5	6.9	9.2	8.8	7.2	7.9	9.6	7.5	7.4
11	9.6	8.5	8.9	7.7	7.3	5.9	5.9	5.1	6.2	8.2	9.9	10.1
12	9.6	9.3	8.5	7.9	4.7	3.4	2.4	2.8	3.5	6.0	9.0	9.8
13	12.3	10.8	9.9	6.7	5.1	3.3	2.0	1.7	3.5	6.1	9.0	11.8
14	6.3	6.2	5.74	.6	3.0	1.5	1.0	1.11	.7	3.2	5.1	7.7
15	4.7	4.9	4.0	3.4	2.6	1.6	0.8	1.1	2.0	3.0	4.3	5.3
16	3.8	3.4	3.0	3.0	1.8	1.1	0.6	1.1	2.1	2.9	3.0	4.0
17	2.7	2.7	1.7	1.4	1.8	1.5	3.15	.0	4.0	3.6	4.8	4.3

[1] *The directions are clockwise starting with 1 = north. Direction 17 represents calm periods.*

SUMMARY

These data provide detailed wind statistics useful for many purposes. Wind speed and wind direction need to be known by natural resources scientists and managers. Our immediate use is for the wind component in potential evapotranspiration models and for modelling wind erosion prediction systems.

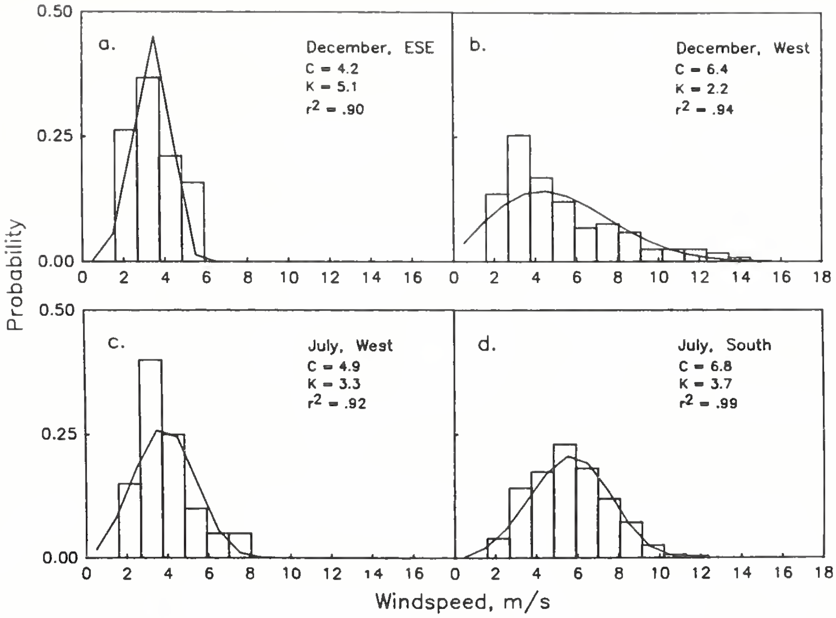

Figure 2. Wind speed distributions from summarized data (bar graph) compared to Weibull calculated distributions for various combinations of months and wind direction, Lubbock, Texas.

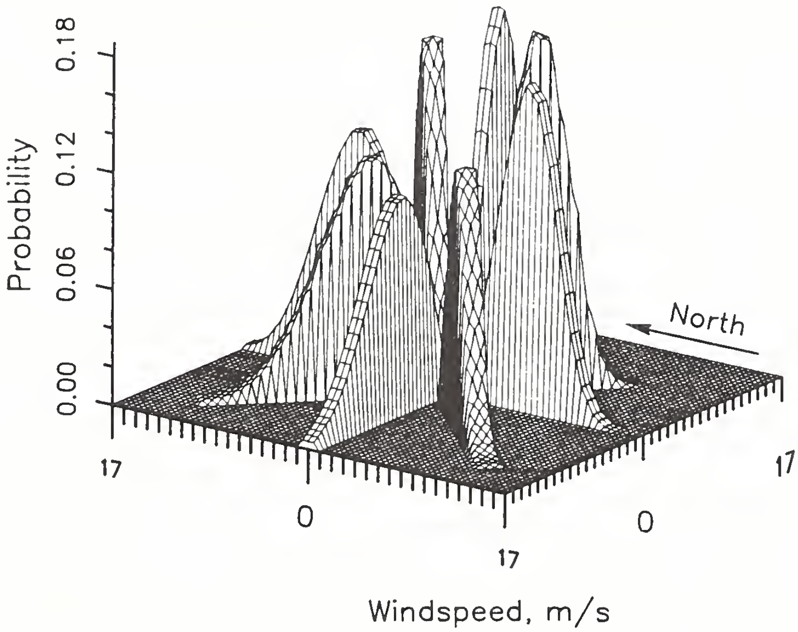

Figure 3. Wind speed probability distributions, Lubbock, Texas, March.

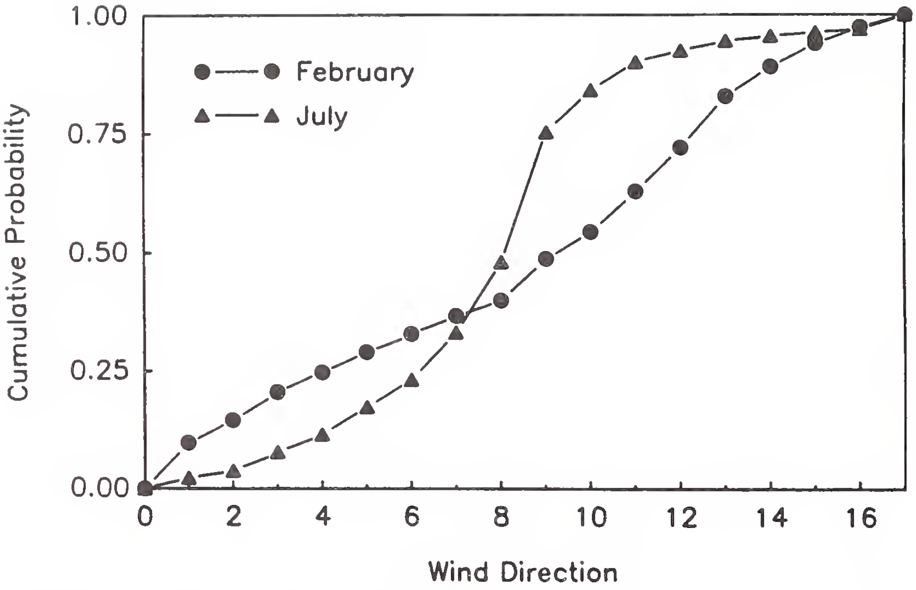

Figure 4. **Wind direction probability distributions for Lubbock, Texas.**

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APPENDIX A

Selected wind station data for the Great Plains States (WERIS).*

Lat		Long		Elev	Period[1]		Obs	Anem. Ht	Loc	WBAN Code	Type	Station Name	St
dd	mm	ddd	mm	(m)	Start	End		(m)					
40	07	103	10	1399	480101	541231	A	8.8	R	24015	F	Akron	CO
37	27	105	52	2298	591020	781231	C	10.1	G	23061	W	Alamosa	CO
38	49	104	43	1857	670401	781231	A	6.7	G	93037	W	Colorado Springs	CO
39	42	104	45	1697	500801	590331	C	19.8	R	93032	N	Denver	CO
39	46	104	53	1622	531016	600707	A	21.9	R	23062	W	Denver/Stap. Inter. Air.	CO
39	39	106	55	1982	480101	641231	A	18.6	R	23063	F	Eagle	CO
39	07	108	32	1474	500228	640919	A	17.7	B	23066	W	Grand Junction	CO
38	03	103	31	1278	550607	640409	A	9.8	R	23067	F	La Junta	CO
38	14	104	38	1465	480101	540630	A	11.0	R	23068	W	Pueblo	CO
38	17	104	31	1421	620319	781231	A	6.7	G	93058	W	Pueblo	CO
37	15	104	20	1753	570201	640930	A	13.1	R	23070	F	Trinidad	CO
37	40	95	29	299	591201	641231	A	16.2	R	13981	F	Chanute	KS
39	33	97	39	449	620601	781231	A	6.4	G	13984	W	Concordia	KS
37	46	99	58	796	610421	781231	A	6.1	G	13985	W	Dodge City	KS
39	03	96	46	324	610401	701231	A	4.0	G	13947	A	Ft. Riley	KS
39	22	101	42	1112	500609	640322	A	9.4	R	23065	W	Goodland	KS
37	55	97	54	479	521001	580431	A	18.3	R	93905	N	Hutchinson	KS
38	50	94	53	328	590915	700131	A	4.3	G	93909	N	Olathe	KS
38	52	98	49	568	530824	641231	A	8.8	R	93997	F	Russell	KS
38	48	97	38	392	560401	650531	A	4.3	G	13922	A	Salina	KS
39	04	95	38	269	640810	781231	A	6.1	G	13996	W	Topeka	KS
38	57	95	40	324	580401	701231	A	4.0	G	13920	A	Topeka/Forbes	KS
37	39	97	25	404	540101	641231	A	9.4	G	03928	W	Wichita	KS
37	38	97	16	432	480101	531130	A	21.3	R	13998	W	Wichita	KS
37	37	97	16	414	600905	701231	A	21.3	R	03923	A	Wichita/McCon	KS
45	48	108	32	1092	650101	781231	A	7.6	G	24033	W	Billings	MT

45	57	112	30	1689	4801C1	601231	A	18.0	R	24135	F	Butte	MT
48	36	112	22	1174	591004	781231	A	6.1	G	24137	F	Cut Bank	MT
45	15	112	33	1592	510619	631029	A	9.1	R	24138	F	Dillon	MT
48	13	106	37	696	680601	781231	A	6.1	G	94008	W	Glasgow	MT
48	24	106	31	853	610608	680630	A	4.0	G	94010	A	Glasgow	MT
47	31	111	10	1056	580401	681130	A	4.6	G	24112	A	Great Falls	MT
47	29	111	21	1124	480101	590202	A	22.9	R	24143	W	Great Falls	MT
48	33	109	46	788	670101	781231	A	6.1	G	94012	W	Havre	MT
46	36	112	00	1188	610920	781231	A	6.1	G	24144	W	Helena	MT
48	18	114	16	908	640701	781231	A	6.1	G	24146	W	Kalispell	MT
47	03	109	27	1236	491221	620815	A	10.4	R	24036	F	Lewiston	MT
45	40	110	32	1399	480101	530704	A	17.4	B	24150	F	Livingston	MT
46	26	105	52	802	480101	641231	A	12.2	G	24037	F	Miles City	MT
46	55	114	05	980	650101	781231	A	6.1	G	24153	W	Missoula	MT
47	11	114	52	823	480101	531130	A	17.7	B	24159	W	Superior	MT
45	52	112	06	1311	480101	541231	A	9.1	G	24161	F	Whitehall	MT
42	51	103	00	1046	480101	541231	A	17.7	B	24017	F	Chadron	NE
40	58	98	19	567	611202	781231	A	6.1	G	14935	W	Grand Island	NE
40	51	96	46	364	720901	781231	A	6.1	G	14939	W	Lincoln	NE
41	59	97	26	472	480101	590909	C	11.0	R	14941	W	Norfolk	NE
41	08	100	41	848	640812	781231	A	6.1	G	24012	W	North Platte	NE
41	18	95	54	304	630401	781231	A	6.1	G	14942	W	Omaha	NE
41	07	95	54	312	600501	701231	A	3.7	G	14949	A	Omaha/Offutt	NE
41	52	103	36	1204	640802	781231	A	6.1	G	24028	W	Scottsbluff	NE
41	08	103	02	1231	491221	541231	A	7.9	R	24030	F	Sidney	NE
46	46	100	45	507	611017	781231	A	6.1	G	24011	W	Bismarck	ND
46	47	102	48	792	481201	640728	A	9.1	R	24012	F	Dickinson	ND
46	54	96	48	278	610626	781231	A	6.1	G	14914	W	Fargo	ND
47	56	97	05	259	491105	581231	A	14.3	R	14916	W	Grand Forks	ND
46	55	98	41	456	481201	541231	A	8.8	R	14919	W	Jamestown	ND
48	16	101	17	526	620629	781231	A	6.1	G	24013	F	Minot	ND
48	25	101	20	504	600501	650228	A	5.5	G	94011	A	Minot	ND
48	11	103	38	581	670823	781231	A	3.1	G	94014	W	Williston	ND
48	09	103	37	578	500301	611231	C	15.2	R	24014	W	Williston/Wbo	ND

Lat dd	 mm	Long ddd	 mm	Elev (m)	Period[1] Start	 End	Obs	Anem. Ht (m)	Loc	WBAN Code	Type	Station Name	St
32	51	106	05	1241	590501	701231	A	4.0	G	23002	A	Alamogordo	NM
35	03	106	37	1620	650316	781231	A	11.9	R	23050	W	Albuquerque	NM
32	20	104	16	990	480701	541231	A	15.2	R	93033	F	Carlsbad	NM
34	23	103	19	1305	600701	691031	A	4.0	G	23008	A	Clovis	NM
31	49	107	28	1229	480701	541231	A	8.5	G	23058	F	Columbus	NM
36	45	108	14	1677	530323	641231	A	10.4	R	23090	F	Farmington	NM
35	31	108	47	1971	730101	781231	A	6.1	G	23081	W	Gallup	NM
32	41	103	12	1123	480701	541231	A	10.7	R	93034	F	Hobbs	NM
32	22	106	29	1292	570901	621231	A	4.6	G	23039	A	Las Cruces	NM
35	39	105	09	2092	480701	641231	A	7.9	R	23054	F	Las Vegas	NM
35	05	106	01	1900	480701	541231	A	8.2	G	23056	F	Otto	NM
36	45	104	30	1945	480701	530831	A	8.5	R	23052	W	Raton/Crews	NM
33	24	104	32	1106	510501	600730	A	15.8	R	23043	W	Roswell	NM
33	18	104	32	1110	570401	630331	A	4.6	G	23009	A	Roswell/Walk.	NM
35	37	106	05	1934	480701	541231	A	8.5	R	23049	F	Santa Fe	NM
33	14	107	16	1471	500601	641231	A	7.3	R	93045	W	Truth Or Con.	NM
35	11	103	36	1237	590918	781231	A	6.7	G	23048	F	Tucumcari	NM
35	06	108	48	1965	581014	721231	A	9.8	R	93044	W	Zuni	NM
34	39	99	16	414	560803	701231	A	3.7	G	13902	A	Altus	OK
34	18	97	06	264	480701	541231	A	9.1	R	13965	F	Ardmore	OK
35	22	99	12	588	580801	690331	A	4.0	G	03932	A	Clinton	OK
36	20	97	54	393	490101	590131	A	11.6	t	13909	A	Enid	OK
34	39	98	24	369	600720	701231	A	4.0	G	13945	A	Ft. Sill	OK
36	18	99	46	669	480701	641231	A	7.6	R	13975	F	Gage	OK
35	00	99	03	474	490201	541231	A	8.2	R	93986	W	Hobart	OK
35	25	97	23	384	590401	701231	A	4.0	G	13919	A	Oklahoma City	OK
35	24	97	36	391	651028	781231	A	6.1	G	13967	W	Oklahoma City	OK
36	44	97	06	309	480701	541231	A	20.4	G	13969	F	Ponca City	OK
36	12	95	54	204	601228	781231	A	7.0	G	13968	W	Tulsa	OK
45	27	98	26	396	640701	781231	A	6.1	G	14929	W	Aberdeen	SD
44	23	98	13	392	620110	781231	A	6.1	G	14936	W	Huron	SD
44	03	101	36	673	480101	541231	A	8.2	R	24024	F	Philip	SD
44	23	100	17	525	620607	781231	A	6.1	G	24025	F	Pierre	SD
44	03	103	04	966	501101	641231	A	9.8	R	24090	W	Rapid City	SD

44	09	103	06	980	550721	701231	A	4.0	G	24006	A	Rapid City	SD
43	34	96	44	437	611125	781231	A	5.2	G	14944	W	Sioux Falls	SD
44	55	97	09	527	480909	541231	A	7.6	R	14946	W	Watertown	SD
32	26	99	41	537	600505	781231	A	6.1	G	13962	W	Abilene	TX
32	26	99	51	542	620501	701231	A	4.0	G	13910	A	Abilene/Dyess	TX
27	44	98	02	55	480701	541231	A	8.2	R	12932	F	Alice	TX
35	14	101	42	1099	610503	781231	A	7.0	G	23047	W	Amarillo	TX
30	18	97	42	183	610701	781231	A	6.1	G	13958	W	Austin	TX
30	12	97	40	155	620906	701231	A	5.2	G	13904	A	Austin/Bergs	TX
28	22	97	40	62	620201	720228	A	4.3	G	12925	N	Beeville	TX
32	14	101	30	784	590507	701231	A	4.6	G	23005	A	Big Spring	TX
25	54	97	26	10	480701	610120	A	17.1	R	12919	W	Brownsville	TX
30	40	96	33	84	511001	580630	A	7.3	R	13905	A	Bryan	TX
27	46	97	30	17	600916	781231	A	7.0	G	12924	W	Corpus Christi	TX
27	41	97	17	6	610713	720228	A	3.7	G	12926	N	Corpus Christi	TX
27	41	97	27	14	490201	580331	A	26.2	R	12946	N	Corpus Christi	TX
28	27	99	13	141	491001	541231	A	8.2	R	12947	F	Cotulla	TX
36	01	102	53	1217	481201	540914	A	19.2	R	93042	F	Dalhart	TX
32	44	96	58	143	660814	781231	A	4.6	G	93901	N	Dallas	TX
32	51	96	51	159	580429	740131	A	6.1	G	13960	W	Dallas/Love	TX
29	22	100	55	314	640301	781231	A	7.0	G	22010	W	Del Rio	TX
29	22	100	47	327	530630	590326	A	12.2	R	22001	A	Del Rio/Laug	TX
31	48	106	24	1200	480701	610430	A	25.9	R	23044	W	El Paso	TX
31	50	106	24	1196	560101	660430	A	4.0	G	23019	A	El Paso/Biggs	TX
31	04	97	49	312	650101	700630	C	3.0	G	03902	A	Ft. Hood	TX
31	08	97	43	280	650501	700630	A	5.5	G	03933	A	Ft. Hood	TX
32	50	97	03	175	530501	630522	A	25.9	R	03927	W	Ft. Worth	TX
32	46	97	27	188	570501	701231	A	4.0	G	13911	A	Ft. Worth	TX
29	16	94	51	8	480701	581217	A	14.0	R	12923	W	Galveston	TX
29	59	95	21	37	690601	781231	A	6.1	G	12960	W	Houston	TX
29	39	95	17	16	500621	600728	A	26.5	R	12918	F	Houston/Hobby	TX
30	30	99	46	521	500401	641231	A	7.3	R	13973	F	Junction	TX
27	30	97	48	18	670201	781231	A	6.1	G	12928	N	Kingsville	TX
27	32	99	28	154	650401	701231	A	6.1	G	12907	A	Laredo	TX

Lat		Long		Elev	Period[1]		Obs	Anem. Ht	Loc	WBAN Code	Type	Station Name	St
dd	mm	ddd	mm	(m)	Start	End		(m)					
27	32	99	28	154	470623	610228	A	11.9	R	12920	W	Laredo	TX
33	39	101	50	990	500628	641231	A	20.7	R	23042	W	Lubbock	TX
33	36	102	03	1015	641103	701231	C	3.0	G	23021	A	Lubbock/Reese	TX
31	14	94	45	89	480901	560330	A	7.9	R	93987	F	Lufkin	TX
30	15	103	53	1481	480701	541231	A	17.1	R	93035	F	Marfa	TX
31	56	102	12	871	591204	781231	A	6.7	G	23023	W	Midland	TX
32	47	98	04	286	480601	641231	A	8.5	R	93985	F	Mineral Wells	TX
28	43	96	15	5	490401	581231	A	8.5	R	12935	F	Palacios	TX
29	57	94	01	9	601118	781231	A	6.1	G	12917	W	Port Arthur	TX
26	10	97	20	9	600725	610531	d	4.0	G	12957	N	Port Isabell	TX
31	22	100	30	585	610915	781231	A	6.1	G	23034	W	San Angelo	TX
29	23	98	34	208	590116	701231	A	4.0	G	12909	A	San Antonio	TX
29	32	98	17	230	600501	701231	A	4.0	G	12911	A	San Antonio	TX
29	32	98	28	243	610901	781231	A	7.0	G	12921	W	San Antonio	TX
29	21	98	27	182	530701	600331	A	21.6	R	12931	A	San Antonio	TX
29	53	97	52	178	510501	560831	A	7.9	R	12910	A	San Marcos	TX
33	43	96	40	233	570401	701231	A	4.3	G	13923	A	Sherman	TX
32	22	95	24	173	500504	541231	A	21.6	R	13972	W	Tyler	TX
28	51	96	55	33	640701	781231	A	6.1	G	12912	W	Victoria	TX
28	47	97	05	35	530828	610530	C	11.6	R	12922	W	Victoria/Aloe	TX
31	37	97	13	157	640218	781231	A	7.0	G	13959	W	Waco	TX
31	38	97	04	145	580501	660731	A	4.0	G	13928	A	Waco/Connally	TX
33	58	98	29	307	610424	781231	A	6.4	G	13966	W	Wichita Falls	TX
31	47	103	12	858	480701	541231	A	9.1	R	23040	W	Wink	TX
42	55	106	28	1622	640812	781231	A	6.1	G	24089	W	Casper	WY
41	09	104	49	1871	650101	781231	A	10.1	G	24018	W	Cheyenne	WY
42	45	105	22	1486	480101	541231	A	17.7	B	24019	W	Douglas	WY
41	24	110	25	2136	480101	541231	A	18.3	u	24118	W	Ft. Bridger	WY
42	49	108	44	1697	620401	730919	A	9.8	R	24021	W	Lander	WY
41	19	105	41	2217	480101	541231	A	19.5	u	24022	W	Laramie	WY
41	48	107	12	2067	550101	641231	A	8.5	R	24057	W	Rawlins	WY
41	36	109	04	2056	600727	781231	A	6.1	G	24027	F	Rock Springs	WY
44	46	106	58	1203	640903	781231	A	6.1	G	24029	W	Sheridan	WY

[1] Format for PERIOD is yymmdd--year/month/day.

* Stations are grouped alphabetically by state name. The WBAN station code is a unique identification code number for each station. Other codes are as follows:

LAT = Latitude
dd = degrees
mm = minutes

LONG = Longitude
ddd = degrees
mm = minutes

ELEV = Elevation above mean sea level in meters

PERIOD = Period of record
yy = year
mm = month
dd = day

NOTE: The change in observation frequency from hourly to 3-hourly occured near the end of 1964, 1970, and 1972 for civilian agencies, Air Force, and Navy, respectively.

OBS = Number of hours/day observations were taken
A = 24
B = 19-23
C = 12-18

LOC = Type of structure on which the anemometer was located
R = Roof-Top
G = Ground Mast
B = Beacon Tower
U = Unknown Location
E = Estimated Wind, No Anemometer

TYP = Type of agency responsible for operation
A = Air Force
N = Navy
W = Weather Service
F = FAA

ANEM. HT = Anemometer height above ground in meters