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# FORUM

## Dynamic Cropping Systems: An Adaptable Approach to Crop Production in the Great Plains

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### ABSTRACT

**Research to integrate the vast array of information needed by producers to make decisions allowing them to remain sustainable in our ever-changing agricultural environment is in its infancy. Present research has not provided crop production and soils information that is adequately comprehensive and holistic for producers to make critical decisions. We propose a dynamic cropping systems approach to help producers make those critical decisions they need to remain sustainable. Our definition of a dynamic cropping system is a long-term strategy of annual crop sequencing that optimizes crop and soil use options and the attainment of production, economic, and resource conservation goals by using sound ecological management principles. Implicit to this strategy is the need for producers to possess information necessary to respond to continual change. Key factors associated with dynamic cropping systems are diversity, adaptability, reduced input cost, multiple enterprise systems, and awareness of environment and information. Development of a dynamic cropping systems research program involves creating a crop portfolio, crop sequence evaluation, and multidirectional flow of information among research, extension, and producers. Dynamic cropping systems approach relies on responsiveness and provides producers with management flexibility for developing their own long-term sustainable crop, soil, and land use systems.**

> *The wise adapt themselves to circumstances, as water moulds itself to a pitcher.*
>
> Chinese Proverb

Crop production occurs in an environment that is always changing. With every growing season, producers must attend to numerous factors that influence their management decisions. Some factors are within the control of producers; many are not. The weather, market conditions, input prices, government programs, and new technology and information represent broad categories of externalities that producers must deal with on a continual basis (Fig. 1). This is a daunting challenge, especially when one considers that producers' decisions are carried out in a financial environment of diminishing economic returns, where one wrong decision could mean financial hardship and potentially the end to a way of life.

To meet this challenge, producers must manage externalities by arriving at decisions that optimize the outcome of multiple goals. This is not a simple task. Producers need to possess the ability to integrate vast amounts of information on externalities that are constantly changing. The information needs to be understood well enough to take advantage of situations in which externalities interact (e.g., choosing an appropriate crop to take advantage of abundant [or deficient] soil water). Furthermore, the information must be translated within the context of the resources available to each producer. In a way, producers' minds have to operate like a multiple-objective decision model, where information on a vast array of elements is quantified and weighted to arrive at a decision (Hwang and Masud, 1979). To do this successfully, however, producers need timely research information relevant to their production system. Research is just beginning to address the vast array of information needed by producers to arrive at decisions that will enable them to remain sustainable in our ever changing environment. Present research has not provided adequate crop and soil production information for producers to make these critical decisions. Some of these tools include producer friendly models and software, as well as site specific farming management techniques.

### Evolution of Cropping Systems in the Great Plains

Providing timely, relevant information on crop production options has been a primary objective of agricul-

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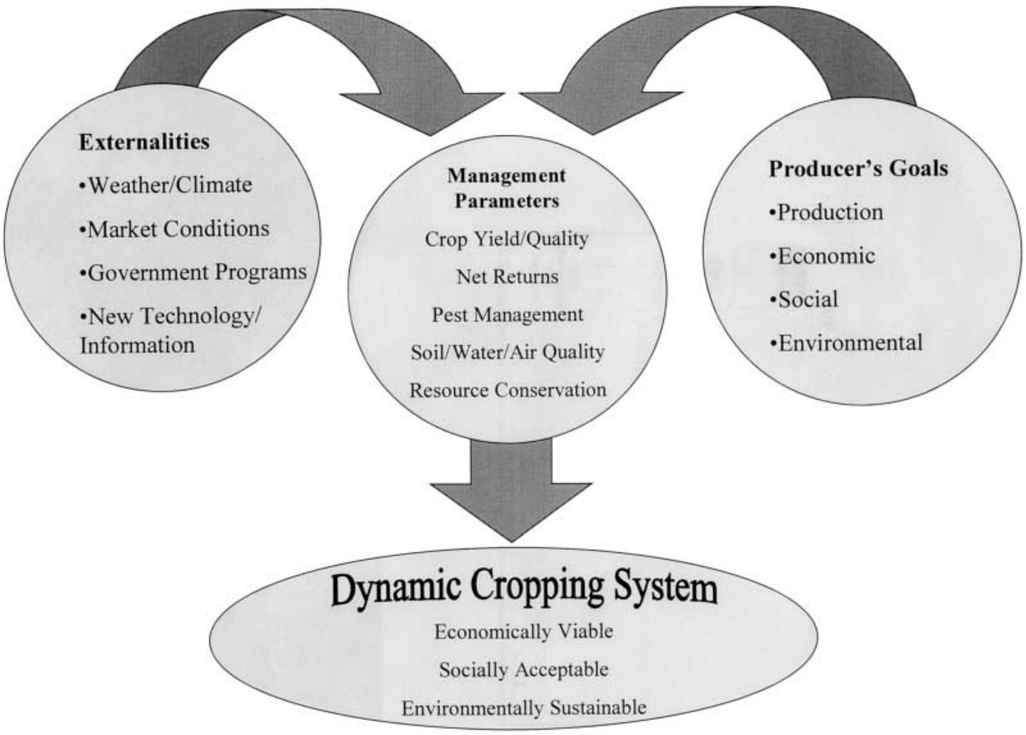


**Fig. 1. A dynamic cropping system involves assessing numerous interactive factors in order to arrive at the best cropping option for an individual producer.**

tural research in the USA for more than a century. In the early part of the 20th century, research locations were established throughout the Great Plains to determine the effect of crop rotations and tillage on crop production under dryland conditions (Chilcott, 1927; Haas et al., 1957). All of these crop rotations had a specific order the crops followed. Although crop diversity was rather limited over much of the Great Plains, this early research recognized the beneficial effects of crop rotation on crop production. Yield differences associated with crop rotation was referred to as the *rotation effect*—the portion of the yield that researchers were unable to explain by known effects involving a single crop (Higgs et al., 1990; Crookston, 1995). In this early research, a limited number of crops were rotated on the same land for a number of years. This type of cropping system has been termed a *fixed-cropping system or rotation* (Black et al., 1974). Rotations with one or two crops plus annual fallow in a cropping system begin to take on characteristics of a virtual monoculture in the long-term (Crookston, 1995). Subtle weaknesses of these limited fixed-cropping systems dominate and the system mimics a monoculture. Specific weed, disease, and insect pests are encouraged with this near-monocultural system, and the system is not as responsive as diverse systems to externality stresses such as weather. These systems lack adequate crop diversity and in the long-term may not be sustainable (Zentner et al., 2001).

Limited crop selection and a prolonged drought from 1912 and 1921 led to a wheat–fallow system that dominated throughout the Great Plains. After the 1930s dust bowl, higher wheat prices, advances in agricultural mechanization, and improved methods for weed control allowed the wheat–fallow system to continue (Black et al., 1974; Greb, 1979). The wheat–fallow system, an example of a fixed cropping system, required limited equipment and demanded little from producers with respect to management skills, and as a consequence had been popular in the Great Plains region (Greb, 1983).

Ongoing agricultural research developed management practices to store soil water and control soil erosion during the fallow period. Improved residue management techniques to store soil water during the fallow period increased wheat yields 2.5-fold in the central Great Plains and had no significant increase in the northern Great Plains (Greb, 1983; Tanaka and Aase, 1987; Tanaka, 1989). Unfortunately, increased soil water storage also resulted in saline-seep problems in some regions of the Great Plains, threatening soil and water resources (Halvorson and Black, 1974). Cropping systems that reduced the frequency of fallow were needed to use the increased soil water more efficiently. To help producers make decisions as to whether to plant a crop or fallow based on the soil water status at planting, flexible cropping systems were developed (Brown et al., 1981; Zentner et al., 1993). These systems allowed producers to decide between planting a crop annually or fallowing the land.

Cropping systems that reduce the frequency of fallow have improved precipitation use efficiency with beneficial influences to the environment. In their review on precipitation use, Peterson et al. (1996) indicated that after winter wheat harvest, no-till managed soils stored as much soil water by spring as those that were fallowed. Even in drought conditions, no-till enhanced aboveground and belowground biomass production of wheat, with the relative advantage of no-till over conventional till being less during years of average or above-average conditions (Tanaka, 1989; Merrill et al., 1996.) Management techniques that enhance soil water storage after harvest and during the winter and spring result in surface soils having near field capacity water content by spring planting, thereby making it possible to produce crops on an annual basis (Farahani et al., 1998). With improved methods of soil water storage and increased use of conservation tillage, cropping systems more intensive than the wheat–fallow system have been developed (Greb, 1983; Tanaka and Anderson, 1997). Due to economic outcomes, government programs, and a perceived need among producers and researchers for additional cropping options, the number and diversity of crops in Great Plains cropping systems has increased (Peterson et al., 1996). Annual cropping, which includes diverse crops such as oilseeds, pulses, and forages, has become a viable option for producers. At the same time, improved technology (planting and residue management technology, herbicides, techniques to improve soil–water management, improved germplasm, etc.) produced advances in management practices for cropping systems. With current residue and crop production management techniques, cropping systems can include a multitude of crop species, thereby allowing producers to increase their cropping options and potentially reduce the risk over a monoculture system (Helmers et al., 2001).

## Dynamic Cropping Systems Concept

The Freedom to Farm Act of the 1990s changed the cropping systems plans of producers and resulted in systems with greater crop diversity in the Great Plains. While these producer changes were occurring, research could not respond in a timely manner to answer producer management parameter questions regarding externalities (Fig. 1). In the past, the goal of research was to make comparative studies rather than develop better ecological–agricultural systems that use technological advances (Raupp, 1994). Information on these types of agricultural systems pose significant challenges for researchers.

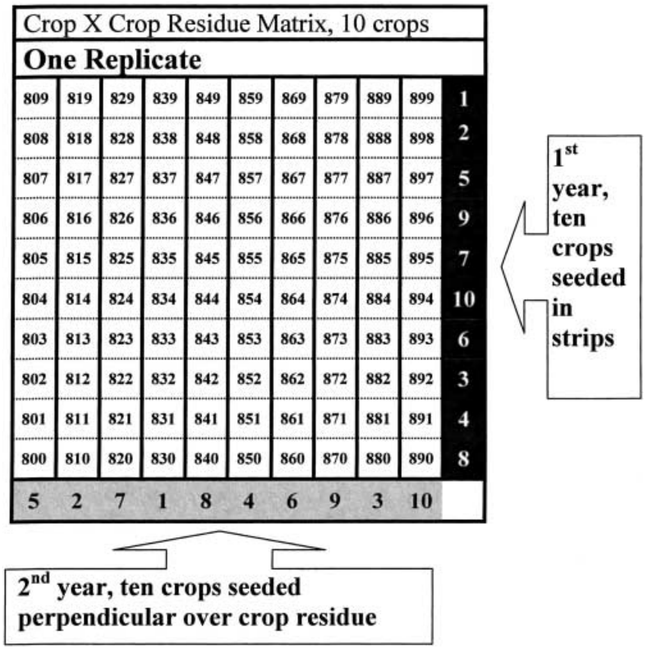
Therefore, we developed the dynamic cropping systems concept to promote the advancement of agricultural systems research and determine causal relationships in solving producer problems. Our definition of a dynamic cropping system is a long-term strategy of annual crop sequencing that optimizes cropping options and the outcome of production, economic, and resource conservation goals by using sound ecological management principles. Key factors of dynamic cropping systems are:

1. Diversity—increase in the type and number of crop species grown and the variety of products produced within an enterprise to reduce economic risk, e.g. cool and warm season oilseeds, pulse crops, cool and warm season grasses;
2. Adaptability—willingness to take advantage of new opportunities and enhance production practices, e.g. no-till seeding, better pest control, and inclusion of oilseed and pulse crops;
3. Reduce input cost—greater net return for each dollar invested, e.g., use of pulses in the systems;
4. Multiple enterprise—several enterprises to exploit favorable markets, e.g., cereal, oilseed, and pulses, possibly livestock;
5. Environmental awareness—producers who are aware of the environment and manage natural resources for future generations, e.g., use of high and low residue producing crops for erosion control, soil test for nutrient management, and integrated pest management;
6. Information awareness—producers accurately evaluate and apply the best incoming information to be competitive, e.g., crops and crop varieties, elements for sustainable agricultural systems, and best management practices.

The first step in developing dynamic cropping systems research is the establishment of a crop portfolio. A *crop portfolio* is regional, usually based on climate, and contains a diverse array of adaptable crop species, economic potential, crop production practices, and soil and water management considerations. The crop portfolio is used to screen adaptable crops for a region and includes the best management practices for production of each adaptable crop.

The second step in development of dynamic cropping systems research, after crops are screened for adaptability within a region, is follow-up research on crop sequencing using information from the crop portfolio. Proper sequencing of crops has long been viewed as crucial for cropping system success (Leighty, 1938; Pierce and Rice, 1988). Experimental designs that allow the simultaneous evaluation of numerous combinations of regionally adaptable crops are needed because only a limited number of crop sequences can be evaluated in fixed-cropping system experiments at one time. The use of a crop matrix technique as a research tool allows evaluation of multiple crop sequences in the same experiment under similar weather and soil conditions. A crop matrix is formed by strip seeding crops into a uniform residue the first year and strip seeding in a perpendicular direction over the residue of the previous year's crop the second year (Fig. 2). Thus, each crop is seeded over the crop residue of all crops included in the matrix. The crop × crop residue matrix determines the synergism or antagonism, in some cases, that occurs among crops. Multiple years are needed to enhance the data set. The crop matrix can be further evaluated the third and fourth years by uniformly seeding a crop each year over the original matrix to evaluate the carryover of rotation effects on crop performance (Krupinsky et al., 2002). A multidisciplinary scientific team approach is needed to evaluate as many of the causative factors of crop sequencing as possible. This information is essential to producers since it provides them with specific crop sequencing guidelines necessary to develop their own crop options.

The third step in dynamic cropping systems approach



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|---|---|---|---|---|---|---|---|---|---|---|
| 809 | 819 | 829 | 839 | 849 | 859 | 869 | 879 | 889 | 899 | 1 |
| 808 | 818 | 828 | 838 | 848 | 858 | 868 | 878 | 888 | 898 | 2 |
| 807 | 817 | 827 | 837 | 847 | 857 | 867 | 877 | 887 | 897 | 5 |
| 806 | 816 | 826 | 836 | 846 | 856 | 866 | 876 | 886 | 896 | 9 |
| 805 | 815 | 825 | 835 | 845 | 855 | 865 | 875 | 885 | 895 | 7 |
| 804 | 814 | 824 | 834 | 844 | 854 | 864 | 874 | 884 | 894 | 10 |
| 803 | 813 | 823 | 833 | 843 | 853 | 863 | 873 | 883 | 893 | 6 |
| 802 | 812 | 822 | 832 | 842 | 852 | 862 | 872 | 882 | 892 | 3 |
| 801 | 811 | 821 | 831 | 841 | 851 | 861 | 871 | 881 | 891 | 4 |
| 800 | 810 | 820 | 830 | 840 | 850 | 860 | 870 | 880 | 890 | 8 |
| 5 | 2 | 7 | 1 | 8 | 4 | 6 | 9 | 3 | 10 | |

**Fig. 2. A crop × crop residue matrix used to evaluate the influences of crop sequence on crop production. During the first year, 10 crops (numbered 1 through 10) are no-till seeded into a uniform crop residue. During the second year, the same 10 crops are no-till seeded perpendicular over the residue of the previous year's crops. Individual plot numbers are assigned for each experimental unit in the replication.**

is the implementation of crop portfolios and crop sequences into long-term sustainable systems. Most long-term cropping systems research is conducted using a fixed-cropping systems approach. This research not only occurs throughout the Great Plains of the USA and Prairie Provinces of Canada (Janzen et al., 1997; Black and Tanaka, 1997; Lyon et al., 1997; Jones et al., 1997), but also in the Corn Belt of the USA (Vanotti et al., 1997; Huggins and Fuchs, 1997; Darmody and Peck, 1997; Varvel, 1994). Currently, research using the dynamic cropping systems concepts is nonexistent, although, Peterson et al. (1993) has used an opportunity cropping treatment in the central Great Plains that approaches the dynamic cropping systems concept. They define *opportunity cropping* as continuous cropping as much as possible without fallow, but not a monoculture, and crop choice depends on stored soil water at a given time. Dynamic cropping systems use crop portfolios and biological synergism and antagonism as well as the landscape-level agroecosystems techniques used by Peterson et al. (1993) to develop cropping systems.

Dynamic cropping systems rely on responsiveness to climatic and biological dynamics. Therefore, scientific knowledge about dynamic cropping systems must be synthesized in a manner that will improve the application of the results in the real world (Weiss and Robb, 1988). In the past, traditional pathways for transfer of research information was unidirectional from research to producer (research → extension → producer). This pathway is no longer satisfactory. At the present, multidirectional flow of information among research, extension, and producers takes a more direct pathway (Jackman, 1986). Multidirectional flow of information allows for feedback from producers and extension to the research team during early stages of a research program so that scientific results have greater application to the real world.

To get this multidirectional flow of information among research, extension, and producers, some type of coupler or decision aid is needed to facilitate the flow of information. In the dynamic cropping systems approach, we developed an interactive computer information product (Crop Sequence Calculator; available at www.mandan.ars.usda.gov; verified 22 May 2002) to help producers assess crop options and sequencing in their own cropping systems (Fehmi et al., 2001; Krupinsky et al., 2001). The multidisciplinary team of research scientists assembled research information to develop guidelines for long-term dynamic cropping systems. This information provides producers with management flexibility that they can use for developing their own dynamic cropping systems. Specific areas covered by the Crop Sequence Calculator are crop production, economics, plant disease, weed management, insects, crop water use and root growth, and surface soil properties. General information on principles for managing pests in dynamic cropping systems and the philosophy of dynamic cropping systems are also included. This interactive computer information product, along with research summaries on the Internet, effectively provides multidirectional flow of dynamic cropping systems information in a timely manner to people in research, extension, and production.

In summary, dynamic cropping systems help producers manage risks in their annual planning exercises for their agricultural systems by providing crop options to increase their returns on investments and by making them more adaptable, diverse, and environmentally aware. The concept of dynamic cropping systems is based on the premise that producers can choose from a variety of crops to optimize their production, economic, social, and environmental goals by effectively responding to externalities beyond their control. As presented, the efficacy of dynamic cropping systems is limited by the availability of knowledge on the performance of crops, crop sequences, and associated management practices under a variety of soils, landscapes, environments, markets, and regulatory conditions. Generating this knowledge represents a significant challenge to the agricultural research community. Creating the informational base to develop dynamic cropping systems requires a multidisciplinary team effort to assess the numerous factors that envelop and affect cropping system performance. New methodologies for evaluating crops and crop sequences are needed, along with the ability to translate scientific results into useable decision aids and information products for producers. However, challenges are also opportunities. The development of dynamic cropping systems represents a change in philosophy for the agricultural research community and an extraordinary opportunity to provide producers with the tools they need to implement economically viable and environmentally acceptable crop production practices, thereby creating a more sustainable agriculture.

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