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SYMPOSIUM PAPERS

Dynamic Cropping Systems: Contributions to Improve Agroecosystem Sustainability

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ABSTRACT

Cropping systems need to be inherently flexible to take advantage of economic opportunities and/or adapt to environmental realities. A dynamic cropping systems concept—characterized by a management approach whereby crop sequencing decisions are made on an annual basis—has been proposed to improve the adaptability of cropping practices to externalities. A symposium on dynamic cropping systems was held at the 2005 ASA–CSSA–SSSA annual meetings in Salt Lake City, UT. Presentations at the symposium reviewed research results from a recent experiment near Mandan, ND, investigating short-term crop sequence effects on crop production, plant diseases, soil residue coverage, and soil water depletion. This paper briefly reviews each of the presentations at the symposium. Future research opportunities on dynamic cropping systems abound, and may have increased impact if emerging issues in agriculture (e.g., increased use of biofuels; livestock integration in cropping systems) are incorporated in evaluations.

Many cropping systems throughout the world are characterized by variable climate and soils, resulting in a high-risk condition for agricultural producers. Such a context applies to the Great Plains of North America, as this region is known for periods of instability due to extreme variability in precipitation and seasonal temperatures. Development of cropping systems that are resilient to these climatic extremes has been, and continues to be, a major challenge to agriculturists in the region.

Cropping systems in the Great Plains have evolved considerably since the arrival of European settlers more than 150 yr ago. Inherently fertile soils were initially mined through intense cultivation to produce crops and forage, only to result in excessive soil erosion and widespread crop failures in times of drought. Efforts to stabilize production of cereal crops in the region led to the adoption of wheat (*Triticum aestivum* L.)–fallow cropping systems. This system, while popular with producers because it required limited equipment and managerial skills, has proven to be agronomically inefficient and environmentally unsustainable, as shown through poor precipitation-use efficiency and decreased soil quality (Farahani et al., 1998; Campbell et al., 1997). Recognition of the drawbacks of wheat–fallow as well as advances in weed and residue management technology led to a reduction in the frequency of fallow in Great Plains cropping systems. Germane to the sustainability of cropping systems that minimize and/or eliminate the use of fallow is the selection and sequencing of crops over time.

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Crop selection and sequencing can take many forms. At a very basic level, crops can be sequenced in a consistent, unchanging pattern, thereby reflecting a fixed-sequence cropping system. Fixed-sequence systems, however, can lead to the development of weed, insect, and disease infestations over time (Krupinsky et al., 2002; Anderson, 2005). Fixed-sequence systems are also less responsive to external stresses such as the weather, and may limit opportunities to take advantage of market conditions and/or government programs. Consequently, fixed-sequences may not be sustainable over the long term. To increase responsiveness to externalities, opportunity/flex cropping systems have been developed (Peterson et al., 2000). These systems allow producers to adjust cropping system intensity and/or diversity based on externalities, such as soil water status at planting (Farahani et al., 1998). Additional flexibility in annual crop sequencing can be realized through the application of a dynamic cropping systems concept (Tanaka et al., 2002), where crop sequencing decisions are made annually based on externalities as well as management goals. This approach to crop sequencing possesses an inherent flexibility to adapt to high-risk conditions, and therefore may be more economically and environmentally sustainable than other approaches to crop sequencing.

A dynamic cropping system represents a long-term strategy of annual crop sequencing that optimizes crop and soil use options to attain production, economic, and resource conservation goals by using sound ecological management principles (Tanaka et al., 2002). Dynamic cropping systems are region-specific, differing in their crop portfolios (i.e., adapted crop species) from one region to another. Critical to the successful implementation of dynamic cropping systems within a region is a thorough understanding of short-term (1–3 yr) crop sequencing effects on relevant agronomic and environmental parameters. Such short-term research efforts can help identify crop sequence *synergisms* and *antagonisms*, thereby providing the necessary foundation for developing strategies to sequence crops over a longer period of time.

At the 2005 ASA–CSSA–SSSA annual meetings in Salt Lake City, UT, a symposium entitled "Dynamic Cropping Systems for Soil and Water Conservation" was held to review results from a recent (2002–2005) experiment conducted near Mandan, ND, investigating short-term crop sequence effects on crop production, plant diseases, soil residue coverage, and soil water depletion. The symposium sought to extend a series of previous symposia focused on dryland cropping systems in the Great Plains of North America (Peterson, 1996; Blade et al., 2002; Lyon and Peterson, 2005), with the intention that the information shared therein could be applied to lower production risks in this inherently risky environment. Below is a brief overview of the papers presented at the symposium, each framed in the context of a guiding question that served as a focal point for this multidisciplinary research effort.

To What Degree Does Crop Diversity Mitigate Production Risks?

As alluded to in the introduction, the Great Plains of North America is a risky environment in which to produce crops because of its highly variable climate. Maintaining economically viable crop yields on an annual basis is challenging and requires an adaptable approach to management, especially in the context of crop selection. In this regard, crop diversification has been an important strategy to address this challenge by broadening the portfolio of crops producers can select in a cropping system (Tanaka et al., 2005). Crop diversification by itself, however, is of limited use without knowledge of how individual crops affect each other in a sequence. Consequently, a thorough understanding of crop sequencing effects—both positive and negative—on agronomic parameters is necessary to optimize cropping system performance.

Previous research in the northern Great Plains has found few consistent positive and/or negative effects of crop sequencing on agronomic parameters (Arshad et al., 2002; Miller et al., 2002; Miller and Holmes, 2005; Krupinsky et al., 2006). Recognizing the need for further exploration on this topic, Tanaka et al. (2007, p. 904–911) evaluated crop sequence effects of 10 crops on crop yield, residue production, and precipitation-use efficiency. These parameters were evaluated using a 10 by 10 crop by crop residue matrix (thereby creating 100 different crop sequences) in central North Dakota. Results from this research allowed for a number of critical questions to be addressed in the context of agronomic performance: How does crop sequence affect relative seed and residue yield? How do individual crops affect precipitation-use efficiency? Which crops are best suited for planting after particularly wet or dry periods? Are there crops that have somewhat stable precipitation-use efficiency under variable conditions? Collectively, this paper provides information to identify crops and crop sequences capable of optimizing precipitation-use efficiency for maximum productivity, and should therefore be of interest to a broad range of clientele, including scientists, crop consultants, and agricultural producers.

How Does Crop Sequence Affect Plant Diseases?

A reduction in traditional wheat–fallow and a concurrent increase in use of no-tillage have contributed to greater cropping system diversity throughout the Great Plains (Tanaka et al., 2002). In a region once dominated by hard red spring wheat, there are currently upward of 16 major crops planted annually (National Agricultural Statistics Service, 2004), with new crops being introduced each year. While this increase in crop diversity has provided producers with greater economic opportunities, it has also increased management demands. Management of plant diseases, in particular, has increased in complexity with additional crops, as each crop possesses unique susceptibilities to pathogens depending on the environment in which it is grown (Krupinsky et al., 2002). Understanding individual crop–environment interactions within diverse cropping systems, then, is essential to minimize plant disease risks.

One of the most effective and inexpensive methods to control plant diseases in cropping systems is through crop rotation (Turkington et al., 2003). Crop rotations lengthen the time between different crop types so pathogens have an opportunity to decline. Specific crop rotation effects on plant diseases, however, are poorly understood. Previous research investigating crop sequence effects on plant diseases in the northern Great Plains found crop sequences with divergent crop types reduced severity of leaf-spot diseases relative to continuous spring wheat (Krupinsky et al., 2006). In contrast, other studies in the region have found limited impact of cropping system diversity on wheat diseases (Bailey et al., 2002; Wang et al., 2002).

Increased knowledge of crop and crop residue effects on plant diseases is needed to optimize management in diverse cropping systems for increased yields and improved crop quality. To help address this need, Krupinsky et al. (2007b, p. 912–920) evaluated leaf spot diseases on spring wheat within a 10×10 crop by crop residue matrix (mentioned previously). Outcomes from this research allowed the following questions to be addressed: To what degree do different crop types (e.g., oilseeds, pulses, cereals) affect the severity of leaf spot diseases of subsequent wheat crops? Do crop and/or crop sequences affect particular pathogens? Does the amount of surface residue coverage left by a crop affect disease severity on spring wheat? Information from this paper should be of interest to agriculturists seeking to decrease production risks from plant diseases in diverse cropping systems. The importance of this type of information is highly relevant in semiarid environments, as foliar and soil- and residue-borne diseases can decrease grain yields by $>30\%$ (Bailey, 1996; Bhathal et al., 2003).

How Does Crop Diversity Affect Residue Cover under No-Till?

Increased crop diversity in the northern Great Plains has resulted in the use of crop species that leave considerably less residue cover on the soil as compared with traditional small grain crops like spring wheat (Merrill et al., 2006). Maintenance of surface residue cover in no-till is essential to optimize cropping system performance, as residue coverage minimizes erosion, enhances retention of limited precipitation, and improves soil quality

(Seta et al., 1993; Tanaka and Anderson, 1997; Wienhold et al., 2006). However, too much surface residue coverage under no-till can increase the incidence of soil- and residue-borne pathogens (Krupinsky et al., 2002), and may contribute to slower vegetative development of crops early in the growing season. Developing a better understanding of specific crop effects on surface residue coverage within no-till cropping systems is essential to ensure appropriate crop sequences are used to accentuate the positive aspects of residue cover while avoiding potentially negative effects.

To better understand the effects of crops and crop sequences on residue coverage of soil in semiarid cropping systems, Krupinsky et al. (2007a, p. 921–930) assessed levels of residue cover for 100 different crop sequence combinations under no-till. In addition to the larger question of how crops and crop sequences affected residue cover, there were a number of important related questions addressed in the paper: What is the carryover effect of high and low residue producing crops on surface residue coverage in subsequent cropping years? How should crops be sequenced in no-till to minimize soil erosion hazards? Information included in this paper should be of interest to agriculturists concerned about maintaining an acceptable amount of residue cover under no-till to optimize agronomic benefits while minimizing potential negative off-site effects.

How Do Crops Differ in Their Capacity to Affect Soil Water Depletion and Recharge?

Soil water availability is often the most limiting resource to crop production in dryland, semiarid cropping systems. In an effort to stabilize yields in these cropping systems, crop–fallow was employed by producers throughout the Great Plains (Farahani et al., 1998). Poor precipitation-use efficiency and reduced soil quality under crop–fallow, however, has resulted in a transition toward annual cropping with a concurrent increase in cropping system diversity (Peterson, 1996). Increased emphasis on crop diversity within annual cropping systems has allowed producers to take advantage of positive agronomic benefits derived from crop sequencing synergisms (Tanaka et al., 2002). Realizing these benefits requires knowledge of soil water depletion and recharge characteristics for individual crops. Such knowledge is especially critical for regions like the Great Plains, where soil water status can vary greatly between growing seasons (Merrill et al., 2004). Such annual variability in soil water status requires producers to select crops for planting that best match anticipated water use by a particular crop with current soil water status and expected precipitation during the course of a growing season.

Evaluations of soil water depletion and recharge by a diversity of crop types are needed in climatically extreme environments to more effectively guide producers' crop selection decisions. Merrill et al. (2007, p. 931–938) investigated the effect of 10 crops under no-till management on soil water depletion and recharge in central North Dakota. Key questions addressed in this research effort included the following: To what degree do different crops deplete soil water, and where in the soil profile does water depletion occur? How do crops differ in their capacity to enhance soil water recharge? What affects do rooting depth and length of growing season have on soil water depletion? Findings in this paper will be of interest to agriculturists wanting to better understand how to most effectively sequence crops in semiarid environments so as to take advantage of available soil water.

How Might Dynamic Cropping Systems Help Address Future Challenges in Agriculture?

Future challenges to achieve agricultural sustainability are immense. Human population growth, fossil energy dependence, climate change, and globalization represent four highly complex realities that will make development of a sustainable agriculture exceedingly difficult during the 21st century (Flannery, 2006; Diamond, 2005; Dukes, 2003). Adapting to future trends brought about by these challenges will require the development and implementation of agricultural production systems that are highly productive, energy efficient, and environmentally nondegrading. Furthermore, such production systems will need to meet these multiple objectives within a context of constant socioeconomic change and environmental flux, which is reflective of the reality under which agriculture exists.

Successfully addressing the aforementioned challenges in agriculture will be no small feat. Tanaka et al. (2002) proposed the application of regionally adapted dynamic cropping systems as one strategy to help address these challenges. Dynamic cropping systems possess the potential to increase management adaptability to externalities through the annual selection of crops and associated management factors to optimize production, socioeconomic, and environmental objectives (Tanaka et al., 2002). The paper by Hanson et al. (2007, p. 939–943) explores potential benefits of dynamic cropping systems in contrast with more traditional approaches to cropping system management. Questions addressed in their paper include the following: In what fundamental ways do dynamic cropping systems differ from fixed-sequence and monoculture cropping systems? What are the potential benefits of adopting dynamic cropping systems? As the final paper in the symposium series, this paper places the preceding field research reports in a broader context, underscoring the value of coordinated, multidisciplinary efforts to better understand crop sequencing effects on agronomic and environmental attributes known to affect agroecosystem sustainability.

Future Research Opportunities with Dynamic Cropping Systems

To date, evaluations of dynamic cropping systems have been concentrated at the USDA-ARS Northern Great Plains Research Laboratory (NGPRL) in Mandan, ND. Evaluations thus far have been short-term, spanning 2 to 4 yr, depending on the types of attributes investigated and research questions asked. Evaluations at NGPRL, while multidisciplinary, have largely been limited to research topics matching the expertise on-site. Consequently, there is much yet to learn in the northern Great Plains to fully understand how different crop sequences affect the myriad of mechanisms contributing to agronomic and environmental outcomes within cropping systems.

While the concept of dynamic cropping systems intuitively makes sense, there is far from broad acceptance of the term within agronomic circles, be it from agricultural scientists or producers. We view this not so much as a flaw in the concept, but rather as a reflection of its recent emergence as a topic within cropping systems research. In light of this, we hope recent investigations of dynamic cropping systems in the northern Great Plains will provide impetus for other scientists to conduct similar research with appropriately scaled crop portfolios. Doing so may contribute to increasing cropping system diversity and extending the length of crop rotations in other regions, potentially improving crop productivity while enhancing land and water resources (Karlen et al., 1994).

Should future investigations be undertaken to develop dynamic cropping systems in other regions, it will be important that researchers carefully consider emerging issues in agriculture when selecting crops and associated management practices for evaluation. The use of crops for biofuels, in particular, has received recent interest as a way to reduce dependence on fossil-based energy (Romm et al., 1998). Understanding rotational benefits and drawbacks of annual and perennial bioenergy crops will be essential to maximize cropping system performance and net energy returns. Perennial bioenergy crops (e.g., *Panicum virgatum* L.) present unique research opportunities in the context of cropping systems management, as there is a need to identify crops, crop sequences, and associated management practices that promote the establishment and subsequent productivity of perennials. Furthermore, guidelines to successfully transition out of perennials back to annual cropping can build on previous research documenting management options for converting Conservation Reserve Program land to crop production (Delate et al., 2002), but research specific to perennial bioenergy crops is needed.

In addition to potential evaluations with bioenergy crops, research is needed to better understand interactions between crops and livestock with the intention of identifying management practices that maximize agroecosystem productivity and operational efficiency. Inclusion of livestock in a cropping system complements both crops and livestock by adding value to grain, improving nutrient-use efficiency, and providing alternative uses for forages and crop residues (Tanaka et al., 2006). Research on integrated crops–livestock systems, however, is challenging, often requiring multidisciplinary research teams that function as cohesive work groups. Research challenges notwithstanding, adding a dynamic livestock component to a dynamic cropping system may create synergisms between the two enterprises resulting in far greater productivity than either enterprise could attain alone.

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