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Design, rationale and methodological considerations for a long term alternative cropping experiment in the Canadian plain region

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ABSTRACT

An interdisciplinary field experiment was initiated to evaluate sustainability of crop production in the Canadian Prairie region. The objective was to develop a resource that would be used to measure change over time associated with input and cropping diversity strategies. The knowledge generated would serve to provide early indications of potential problems and to guide development of improved systems. The study was located near the geographic center of the region on the transition between the semi-arid prairie and the sub-humid parkland regions. The design of the study is reported here, while later papers will report and discuss treatment responses. The study is based on three levels of inputs; organic, reduced and high combined with three levels of cropping diversity: low, diversified annual grains and diversified annual perennial to give a matrix of nine treatments. The site was uniformly cropped and characterized for one year prior to imposition of the treatments, and results used to validate the experimental design. Systems were defined by general principles that incorporate flexibility and allow systems to be changed so they could function in a near optimal state. Several grassland sites and one native prairie site located nearby were characterized as reference points for examining biodiversity and soil quality attributes of the treatments. To accommodate multidisciplinary use of the data, a central database was developed that allows all collaborating scientists to access the data, yet protects data integrity. Overall results to date provide a clear indication that the study provides a resource that is well suited to meet the objectives.

1. Introduction

Most of the grassland ecozone of the Canadian Prairies has been cultivated with only small remnants of native prairie remaining, and all cultivated land has incurred some soil degradation over the past 100 years (Acton and Gregorich, 1995). Prior to 1980, wheat occupied more than 50% of the cultivated area of the prairies, and summer fallow (tillage and/or chemical) was practiced on more than 30% of the area (Statistics Canada, 2006). Almost all crop land was tilled two or more times between harvest of the preceding crop and seeding of annual grains. Most annual grains received chemical fertilizers to correct soil nutrient deficiencies and were treated with one or more chemical pesticides.

Summer fallow and tillage are major contributors to soil degradation and use water very inefficiently (Campbell and Zentner, 1993; Biederbeck et al., 1994). However, their elimination can increase reliance on fertilizer and pesticide inputs. Adoption of conservation tillage allowed for a reduction in summer fallow and tillage while facilitating more diversified cropping (Brandt and Zentner, 1995; Stevenson and Van-Kessel, 1996). Diversified cropping has the potential to positively impact both agronomic and ecological functions within agro-ecosystems. Crop diversification can enhance yield and reduce reliance on pesticides while improving soil quality (Brandt and Zentner, 1995; Gan et al., 2003), but effects are typically slow to develop and difficult to predict. From a pest management perspective, the major factors that influence pest status of insects are weather, habitat, food, and natural enemies. Crop diversification can play a major role in all of these factors (Olfert et al., 2002). The vegetative canopy of a crop can effectively moderate micro-environments. Day-time temperatures are lower and night-time temperatures are higher inside a dense crop canopy than air temperature. Humidity tends to be higher inside a dense crop canopy in more arid regions. As a result, diversified cropping systems provide arthropods with a range of micro-environments to select from to suit the specific requirements for their optimum growth, development and survival (Alteiri, 1994). Similar observations have been noted for other pests like weeds and disease (Derksen et al., 2002; Johnston et al., 2002).

Although agronomic benefits supported initial changes to crop production practices, economic realities have accelerated their adoption (Zentner et al., 2002). Environmental concerns over chemical inputs and movement of their residues to non-target areas have

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been added to the long list of issues shaping how we view crop production. Extensive cultivation of the grassland ecozone poses a significant threat to survival of diverse organisms inherent to the region (Acton and Gregorich, 1995).

Our cropping systems experiment reflects these diverse and often conflicting forces. They can be broadly grouped as organic, low input and high input farms based on input use. They can also be grouped as low diversity farms that rely on summer fallow and cereal monoculture; those that grow a diversity of cereal and broadleaf crops with minimal use of summer fallow, and those that crop a diversity of both annual and perennial crops. Within any input level, farms typical of each of the diversity levels can be found. Thus, farms generally fall into one of the 9 crop diversity × input level systems.

Agro-ecosystem experiments provide good tools to reliably predict the impact of agricultural practices on the land resource and the environment (Rasmussen et al., 1998). They serve to guide development of more appropriate alternatives, and provide early indications of potential problems. While there is a wealth of knowledge generated from rotation and fertility studies in the region (Mitchell et al., 1991; Campbell et al., 1990), these studies have focused on one to several components of cropping systems. Very few studies have looked at whole cropping systems or agro-ecosystems, and even fewer exist in the Canadian Prairie region.

Field studies must be designed to facilitate effective management (Frye and Thomas, 1991) and analysis. Management considerations include: plot sizes need to accommodate equipment or sampling; the impact of having all field traffic in one or two directions; how destructive sampling might affect treatment responses; and how to ensure that treatments are not misapplied. To facilitate appropriate analysis, the need for randomization, for replication and for all rotation phases to be present each year are the three major principles that should guide study design (Brandt, 1945). While managing treatments in the field may be complicated by adhering to these principles, experiments that have survived to become long term and contribute to understanding agro-ecosystems share these three design principles. It is also critical that consideration for statistical analysis be undertaken at the design stage so that the former three principles are met while ensuring statistical integrity (Frye and Thomas, 1991).

The high cost of agro-ecosystem studies prevents them from being repeated at numerous locations. Soil and climate conditions where such studies are located should be broadly representative of the area where results are to be applied (Olesen et al., 2000). Site selection within a location is important to minimize soil variability across the site, with blocking imposed to account for site variability to the greatest extent possible (Frye and Thomas, 1991). Soil factors that should be addressed include those that could exert major influences on the data of greatest importance. Characterization of the site ensures that results are applicable to the area of interest (Cady, 1991), and also provides baseline data for measuring change over time. Characterization of site variability can be highly valuable in interpreting data, and site characterization data can be used as covariates in subsequent statistical analyses of study data. In agro-ecosystem studies, biological changes due to treatments are of particular interest, so characterizing biological properties and variability across the site prior to study initiation becomes important.

Most productive agro-ecosystem studies are evolutionary in nature, so changes to the study over time need to be accommodated (Frye and Thomas, 1991). However, changes can compromise the integrity of such studies, and some have been discontinued for this reason. One strategy to deal with this is to define at the outset, what and when changes to primary treatments or management practices can or should be considered. Having a clear set of primary objectives and a clear understanding of how treatments are structured to accomplish the objectives can set the basis for defining how changes can be instituted.

Most studies undergo incidental changes that are either independent of the treatments imposed, or do not truly reflect the influence of treatments. Unusual weather events and misapplication of treatments are things that we have little influence over after they happen. Such effects need to be well documented as they affect integrity and interpretation of data from the study. Other effects like the degree of soil creep associated with tillage are influenced by plot size and repeat treatments applied in one direction. While these may be difficult to alleviate, they need to be recognized and accounted for to the extent possible.

Such studies should involve individuals from a broad range of disciplines, to generate a comprehensive understanding of how agro-ecosystem system components interact. Interdisciplinary studies of this nature generate vast amounts of data, and data management is a critical consideration. Database design should ensure data integrity and security while facilitating access by collaborating scientists and timely analysis and reporting. Other considerations include whether derived data like reports, papers, posters and presentations need to be included in the database.

Agro-ecosystem studies are very costly to conduct, and require careful attention to ensure their integrity over their planned duration. Consequently selecting appropriate methodologies to use in their design and management becomes a critical consideration. This paper describes the rationale behind initiation of an ongoing cropping system experiment. It also describes how the study is structured and managed, and discusses how the methodologies used have impacted general progress to date. The primary focus of this study was to provide guidelines for the development of sustainable crop production systems on the Canadian Prairies based on the five pillars of Sustainable Land Management (Smyth and Dumanski, 1993). The study is based on comparisons among three levels of inputs applied with three levels of cropping diversity.

2. Materials and methods

2.1. Site characteristics

The study was established in 1994 at Scott, Saskatchewan (52°22′; 108°50′, elevation = 713 m) on a Dark Brown Chernozemic soil on the transition between the semi-arid and sub-humid prairies. Mean annual values for frost free period is 97 days; temperature is 1.0 °C; precipitation is 355 mm; and potential evaporation is 635 mm (Environment Canada). During the growing season (1 May–31 August) mean temperature is 14.5 °C, and mean total precipitation is 234 mm. Site characterization was undertaken to document site soil and biotic characteristics, including variability/uniformity across the site. Site characterization data were also collected on factors that were likely to respond to treatments to provide a reference point for measuring treatment driven change over time. Soil properties and variability were measured on soil cores taken from a planned set of locations across the site in 1994 (Selles et al., 1999). Biological site characterization was done by uniformly cropping the site and conducting weed and arthropod surveys in 1994 on the site and associated grassland sites. Barley was sown on the entire site with a standard rate of nitrogen and phosphorus fertilizer. After seeding, the corners of each plot based on the proposed experimental design were located and marked. In June, prior to herbicide application numbers of each weed species present were counted from twenty 0.25 m^2 areas per plot. Barley yield was determined by direct harvesting a 1.5 m by 36.5 m area from the center of each plot followed by cleaning and weighing of the harvested grain.