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Changes in field-level cropping sequences: Indicators of shifting agricultural practices

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ABSTRACT

Farmers implement an assortment of management practices to ensure the sustainability, economic viability, and resilience of their operation. Dryland farming practices dominate in the semiarid regions of the US northern Great Plains, where historical practice has been to rotate small-grain cereals with whole-year summer fallow; however, pulse crops (e.g., lentils) have become increasingly common in these regions as an alternative to fallow. The area of fallow in northeastern Montana, for example, has decreased by one-third, while the area of pulse crops has increased more than five-fold. Our objectives were: (1) to characterize the principal cropping sequences in northeast Montana during the period of regional pulse crop adoption (2001–2012); and (2) to identify changes in the relative proportions of these sequences during the same period. We identified crops at the field-level by class (cereal, pulse, fallow, or cereal–fallow strips) for 2001–2012 using multitemporal Landsat imagery in conjunction with the cropland data layer, cadastral data, ground reference data, and local producers' records. The annual crop classifications were combined into a 12-character string for each field that represented the sequence of crop classes for 2001–2012. We then searched these strings for specific 2- and 3-year crop sequences with a string-matching algorithm. The most abundant sequences involved continuous cereal, block-managed cereal–fallow, and cereal–pulse. We also observed a steady decrease in the abundance of cereal–fallow sequences managed by strip-cropping that were coincident with increases in block-managed cereal–fallow sequences and with increases in pulse production. We conclude that, over the study's time frame, regional producers grew more cereal crops and fallowed fields less frequently, but did not appear to strongly adhere to specific sequences. Furthermore, strip-cropping as a management practice has declined substantially.

1. Introduction

The area of fallowed cropland in northeastern Montana has decreased by one-third in the past 15 years, while the area devoted to pulse crops has increased nearly five-fold (Lee, 2011). Pulses, leguminous crops grown for their edible seeds, were grown primarily on land formerly in cereal–fallow sequences, managed by strip-cropping (i.e., alternating 50 or 100 m wide strips) or in block-managed rotations and in idle fields returning to production following expired enrollment in the Conservation Reserve Program (CRP). Incorporating pulses into rotational sequences with the region's dominant crop – small grain cereals – improves the robustness and resilience of local agricultural systems (Zentner et al., 2001, 2002; Burgess et al., 2012). The identification of specific rotational sequences is important because they provide an insight into the general long-term sustainability of regional agriculture. Furthermore, determining the prevailing sequences can help establish which ones have been successful and, therefore, which sequences might be more likely to succeed in similar regions.

Management practices affect the sustainability, economic viability, and resilience of an operation. Management practices at the field-level include logistical (e.g., scheduling planting), crop management (e.g., fertilizer rates, water usage), crop (species and variety), cropping systems (e.g., sequences and rotations), and tillage systems (e.g., no till, conservation till, or traditional till) (Meinke and Stone, 2005). We focus on individual fields, because, in most instances, they represent the smallest and most fundamental decision unit for managers.

Climate plays a large role in determining whether a particular management practice is adopted locally and, if adopted, how

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prevalent the practice becomes. In semiarid regions, the established agricultural practices focus primarily on capturing, conserving, and effectively using water (Cochran et al., 2006). Dryland farming practices dominate the drier portions of the U.S. Northern Great Plains (NGP), such as northeastern Montana. Historical practice in these regions has been to rotate small-grain cereals with summer fallow, a practice that entered widespread use in the late 1930s as a means to manage soil water in regions where rainfall is a limiting resource (Cochran et al., 2006). Cultivating pulses as green manure recently has become an increasingly common alternative to summer fallow in rotations with cereals (Miller et al., 2006; O'Dea et al., 2013; Tanaka et al., 2010).

Cereal–pulse sequences include a cereal, typically spring or winter wheat (*Triticum aestivum* L.), durum (*Triticum turgidum* L.), or barley (*Hordeum vulgare* L.), and a pulse crop such as dry pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.), dry bean (*Phaseolus vulgaris* L.), or chickpea (*Cicer arietinum* L.) (Lemke et al., 2007). These sequences provide many field-level benefits including: (1) biological nitrogen (N) fixation, thereby making additional N available to the succeeding crop and reducing fertilizer requirements; (2) substantially lower water requirements than cereals or alfalfa; (3) improved options for controlling weeds; (4) reduced insect and disease problems; (5) improved soil tilth and stability; (6) reduced soil erosion; and (7) improved yields and higher protein levels for the following cereal crop (Cochran et al., 2006; Lee, 2011; Peel, 1998).

Changes in the relative proportions of cereal–fallow (block-managed and strip-cropped) and cereal–pulse sequences have implications for farm productivity and profitability, as well as broader implications in terms of improved environmental quality and economic impacts on surrounding communities (Zentner et al., 2001, 2002). The pulse industry in the northeast Montana counties of Daniels, Roosevelt, Sheridan, and Valley has recently experienced rapid growth. This region cultivated less than 20,000 ha annually through 2003; however, production increased to more than 125,000 ha during the relatively short span of 2004–2006. The area devoted to pulse crops has stabilized since 2006 with little additional growth; however, other regions such as north-central Montana have experienced recent growth (NASS, 2013). The annual economic benefits to these counties have been substantial with more than $100 million directly attributed to the 2010 pulse crop (Lee, 2011). The lessons learned here can be useful to producers in other regions in which the pulse crop potential has yet to be fully realized. The objectives of this work were: (1) to characterize the principal cropping sequences in northeast Montana during the period of regional pulse crop adoption (2001–2012); and (2) to identify changes in the relative proportions of these sequences during the same period.

2. Materials and methods

2.1. Study area

The study area comprises the four most northeastern Montana counties of Daniels, Sheridan, Roosevelt, and Valley (Fig. 1). It is bounded by Saskatchewan to the north, North Dakota to the east, and the Missouri River to the south. Federal and state lands lie along much of the western border and are non-cropland. The region is characterized by low relief and has a semiarid climate (Padbury et al., 2002). Total precipitation averages just over 310 mm annually, occurring primarily as rain between April and September (WRCC, 2013). Maximum daily temperatures in July average 31 °C, while January maximum daily temperatures average −10 °C (WRCC, 2013). The dominant land cover types are shortgrass prairie and agriculture. Regional agricultural practices are primarily dryland systems (Tanaka et al., 2010), although center-pivot irrigation is not uncommon for producers in close proximity to the Missouri River. Agriculture consists largely of cereal crops, primarily spring wheat, and an increasingly substantial area of pulse crops throughout most of the region; however, relatively small amounts of other crops are grown within the Missouri River corridor (NASS, 2012).

2.2. Data

2.2.1. Satellite imagery

Landsat images for 2001–2006 and 2012 were obtained from the Earth Resources Observation and Science Center (EROS). Three Landsat scenes were required for full coverage of the study area: Path 36, Row 26 (36/26); Path 36, Row 27 (36/27); and Path 35, Row 26 (35/26). We used a mid-season mosaic (∼mid-July) and a late-season mosaic (∼mid August) from each year to better capture phenological variation and improve classification. Obtaining cloud-free images of the study area required using imagery from two sensors: the Thematic Mapper (TM) aboard Landsat 5 (2001–2006) and the Enhanced Thematic Mapper Plus (ETM+) aboard Landsat 7 (2001–2006, 2012) (Table 1). The ETM+ images from 2003 onward have data gaps caused by the permanent failure of its scan-line corrector (SLC) (see e.g., Markham et al., 2004); images with these data gaps are known as SLC-off images. Due to the positions of the three overlapping Landsat scenes relative to the study region, data loss due to SLC-off gaps has been estimated at approximately 15% or less (Long et al., 2013).

2.2.2. Ground reference data

Ground reference data from 525 locations were collected during July 2012. The locations were randomly chosen from fields identified as agriculture and that were viewable from public rights-of-way. We recorded location and class (Cereal, Pulse, or Other). Cereal–fallow strip-cropping is not an uncommon practice, particularly in the western portion of the study area; these fields were typically classified as 'cereal'. Some reference sites were unusable because they were: (1) not accessible; (2) not agriculture; (3) duplicate observations of the same field; or (4) cloud covered in both mid-season and late-season images. The final dataset used 434 of the ground reference sites; 278 (64%) were cereal crops, 86 (20%) sites were pulse crops, and 70 (16%) were something else (typically CRP land or, much less frequently, some other crop such as alfalfa). These percentages are similar to regional data from the US Department of Agriculture (USDA) (NASS, 2012).

2.2.3. The cropland data layer

The cropland data layer (CDL) is a geo-referenced raster-based data layer denoting specific agricultural cover types (e.g., wheat, lentil, or corn). It was developed by the USDA's National Agricultural Statistical Service (NASS) primarily to assist in determining seasonal area estimates for major commodity crops (Johnson, 2013; NASS, 2013). The CDL has been used in a wide range of agricultural (e.g., Scheffran et al., 2007; Schultz et al., 2007; Kutz et al., 2012) and environmental (e.g., Linz et al., 2004; Hagen et al., 2005) studies. The CDL extends back to 1997 and is based on medium-resolution satellite data with extensive ground reference data (Boryan et al., 2011; Han et al., 2012). Coverage of the conterminous US for 2008–2012 is complete, while coverage for 1997–2007 depends on the state. Coverage for Montana, for example, dates to 2007, while neighboring North Dakota extends back to 1997.

The CDL is created from a variety of inputs. Imagery inputs are multitemporal and derive from several satellite-based sensors. The list of sensors depends on the year; the CDLs in this study were based on: (1) the Advanced Wide Field Sensor (AWiFS) (2007–2010); (2) TM (2008–2011); (3) Moderate Resolution Imaging Spectroradiometer (MODIS) 16-day NDVI (Normalized