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Research achievements and adoption of no-till, dryland cropping in the semi-arid U.S. Great Plains

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ABSTRACT

The Great Plains region of the United States is an area of widespread dryland crop production, with wheat being the dominant crop. Precipitation in the region ranges from 300 to 500 mm annually, with the majority of precipitation falling during hot summer months. The prevailing cropping system is a two-year rotation of wheat and summer fallow. The adoption of no-till practices has resulted in greater precipitation storage and use efficiency, which has led to greater cropping intensity, higher productivity, more diverse crop rotations, and improvements in soil properties. In Colorado, for example, a no-till rotation of winter wheat–maize–fallow increased total annualized grain yield by 75% compared to winter wheat–summer fallow. Soil erosion was reduced to just 25% of that from a conventional tillage wheat–summer fallow system. The primary challenge with reducing fallow frequency is the increase in yield variability and risk of crop failure. Improved approaches for choosing crop or fallow are being developed based on soil water content and forecasted weather. Development of alternative crops, crop rotations, and integrated livestock systems that are sustainable from both economic and ecological perspectives is an on-going effort. Other research is addressing adaptation of cropping practices to climate change and the potential for dryland biomass crop production for the developing biofuel industry.

1. Introduction

1.1. Geography and climate of the U.S. Great Plains

The U.S. Great Plains is a semi-arid, prairie and steppe landscape with an extensive area of dryland crop production. The area, bounded by the Rocky Mountains on the west and by higher rainfall zones to the east, extends from the Canadian border on the north to the southern part of Texas (Fig. 1). Most cultivated soils in the Great Plains were formed in loess parent materials, have textures of silt loam, silty clay, and loamy sands (Stewart et al., 2010), and are classified as Mollisols, Entisols, Aridisols, Vertisols, and Ustalfs (Aandahl, 1982). The Great Plains is characterized by hot summer days with high sunlight intensity, a summer rainfall pattern, and cold, dry winters (Farahani et al., 1998). The annual precipitation increases sharply from west to east, ranging from just 300 mm east of the Rocky Mountains to >500 mm on the eastern boundary of the semi-arid zone. The east-west precipitation gradient is contrasted by a strong, increasing north to south gradient in potential evapotranspiration (PET). For example, PET is similar in magnitude to the annual precipitation in the northern Great Plains, while PET exceeds 400% of the 400–500 mm annual precipitation in the south. The combination of annual precipitation and PET strongly influences the geographic distribution of cropping practices and production potential.

A major challenge to dryland cropping in the Great Plains is the high level of temporal and spatial climate variability with recurring periods of severe drought. Periodic wet cycles in the Great Plains are countered by droughts such as the decade long drought in the 1930s that caused extensive wind erosion and economic hardship during a time knows as the dust bowl. Severe and prolonged drought recurred in the early 1950s, early 1960s, mid 1970s, and again in the most recent decade. Annual precipitation can vary by more than 100% from year to year. In addition to year to year variability, highly variable, short-term drought periods within the growing season are also common. A major challenge for dryland crop production is to implement management practices that efficiently use precipitation while also minimizing risk of crop failure when precipitation is low or infrequent. No-till management is one management practice used by producers to address these challenges. This paper addresses

Abbreviations: PET, potential evapotranspiration; C, carbon; N, nitrogen; U.S., United States.

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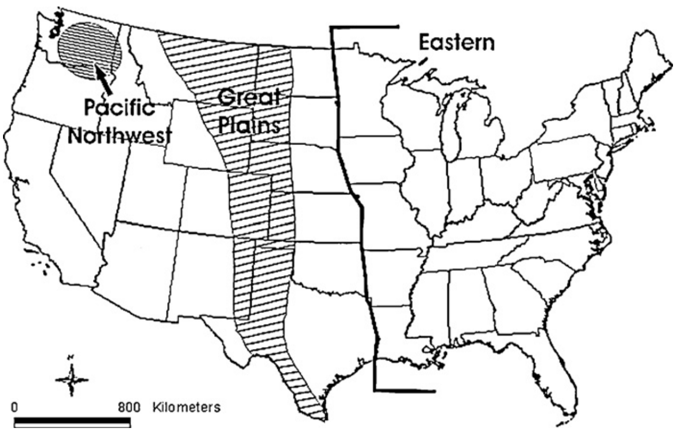

Fig. 1. The Great Plains of the United States.

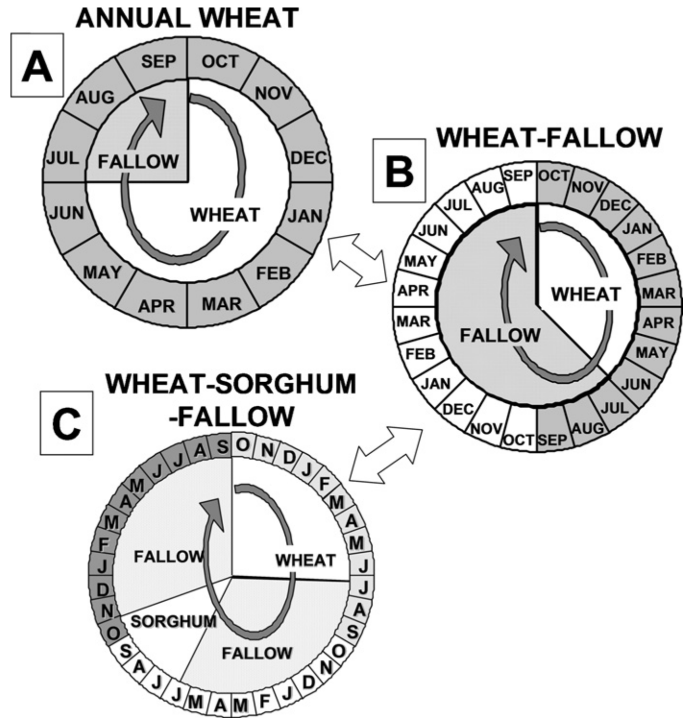

Fig. 2. The annual wheat (A), wheat–summer fallow (B), and wheat–sorghum–summer fallow (C) cropping sequences diagramed as a one-, two- or three-year cycle beginning with wheat establishment in October for the southern Great Plains.

the adoption of no-till, dryland cropping systems in the semi-arid United States Great Plains and also reports on current research developments related to dryland cropping systems.

1.2. Dryland cropping systems in the U.S. Great Plains

The principal dryland crop in the Great Plains is wheat (*Triticum aestivum* L. emend. Thell.). Wheat, as a drought avoidance species, is well suited to the Great Plains because it can take advantage of soil moisture that accumulates during fallow periods, winter, and early spring, and, when planted at optimal timing, matures early enough to avoid hot and dry late summer conditions. Wheat production came into the Great Plains with the westward migration of settlers from more humid regions, where traditional cropping was continuous wheat in monoculture. In the semi-arid Great Plains, continuous wheat systems were prone to failed crop establishment and farmers adopted a wheat–fallow rotation that added a full growing season of fallow ahead of the wheat crop to capture and store precipitation. A continuous winter wheat monoculture in the southern Great Plains is grown during a 9-month period from planting in October to harvest in July, followed by a 3-month fallow before the next wheat planting (Fig. 2A). The short fallow after wheat harvest during a period of high temperatures in the southern Great Plains is prone to failed establishment of the subsequent crop. The winter wheat–summer fallow system in the southern Great Plains adds an additional 12-months to the fallow period, which increased storage of precipitation and reduced risk of failed crop establishment (Fig. 2B). Although the wheat–fallow sequence produces only one crop in two years, it stabilized yields, reduced crop failure, and improved the annualized grain yield at some locations (Greb et al., 1970; Baumhardt and Anderson, 2006). A similar adaptation occurred in the central Great Plains. In the northern Great Plains, spring wheat is grown rather than winter wheat, but a similar wheat–summer fallow rotation was adopted. Spring wheat is typically planted in April and harvested in July, making the fallow period as much as 21 months long in the northern Great Plains. These extended fallow periods, referred to as summer fallow, became the traditional practice in the Great Plains for most of the twentieth century.

While summer fallow minimizes risk of crop failure, there are many sustainability problems associated with extensive fallowing including poor precipitation use efficiency, increased soil erosion, decreased soil organic C and N, and fragile economic returns (Black et al., 1981; Janzen, 1987; Campbell et al., 1990; Wienhold et al., 2006). Precipitation storage efficiency during fallow is poor, ranging from approximately 15 to 40% (Black and Power, 1965; Tanaka and Aase, 1987; Peterson et al., 1996), with reduced and no-till systems accounting for the greater reported values. To address these problems, there has been an evolution of residue management practices in dryland cropping systems in the Great Plains that has reduced the number and type of tillage operations (Lyon et al., 2004). The development of cost effective herbicides and good planting equipment has facilitated the adoption of no-till practices by an increasing number of producers. The adoption of no-till by producers coincided with changes to more intensive crop rotations, with little adoption of no-till among producers following the traditional wheat–summer fallow rotation. Specific tillage methods in the traditional wheat–summer fallow rotation vary, but weed control in conventional tillage generally includes multiple, shallow tillage passes using wide blades or sweeps to control weeds during summer fallow and chisels or disks for seedbed preparation. Strict no-till systems rely on herbicides for weed control and eliminate all soil disturbing operations other than planting. In contrast to strict no-till systems, conservation tillage uses a combination of herbicides and non-inverting tillage to control weeds, which greatly reduces the frequency of tillage and the amount of soil disturbance (Lyon et al., 2004). In 2002, only about one-third of the land in crop production was in a conservation tillage system, and less than half of that was no-till (Lyon et al., 2004). The limited adoption of no-till in traditional systems is related to decreased grain yield with no-till, winter annual grass weeds such as downy brome (*Bromus tectorum* L.) that are difficult to control without tillage, cost of herbicides, and the need for specialized equipment. The greatest adoption of no-till dryland cropping systems has been associated with an intensified crop rotation that reduces or eliminates summer fallow. For example, no-till farmers in the southern Great Plains have adopted a cropping system with two crops in three years by introducing a summer grain crop such as maize (*Zea mays* L.) or sorghum (*Sorghum bicolor* L. Moench) (Fig. 2C). The summer grain crop in the rotation takes advantage of improved soil water storage in no-till while retaining valuable fallow periods.

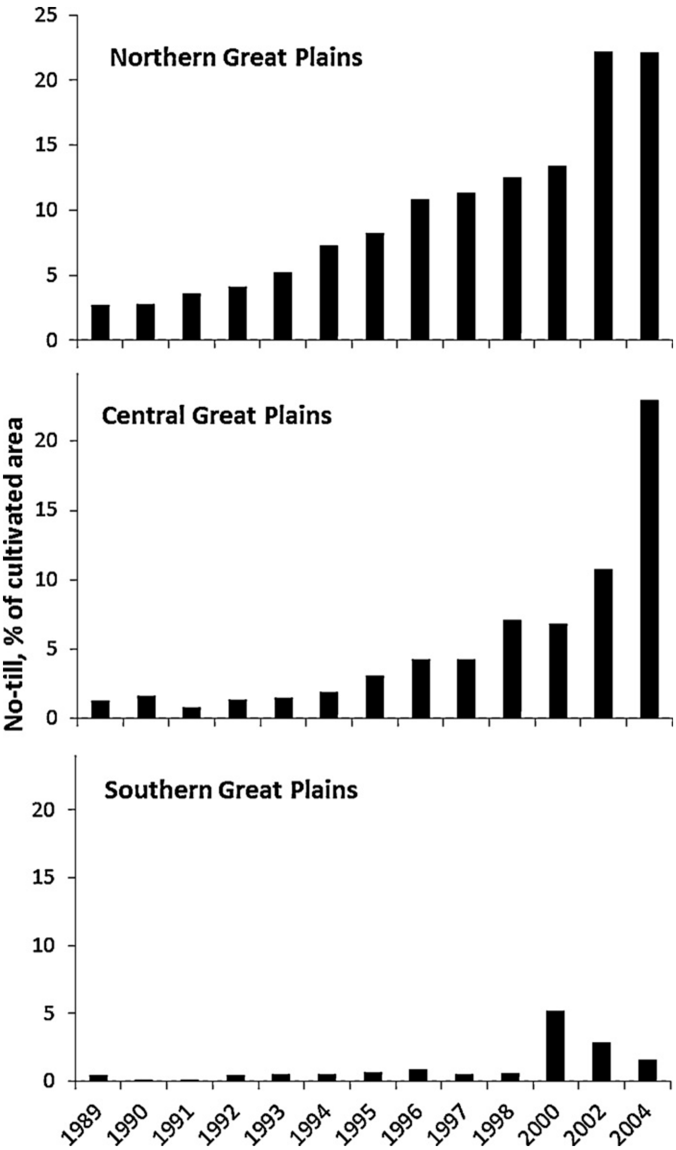

Fig. 3. No-till adoption in the northern Great Plains (represented by counties in NE Montana and NW North Dakota), the central Great Plains (represented by counties in NE Colorado and SW Nebraska) and the southern Great Plains (represented by counties in SE Colorado, SW Kansas, and NW Texas) from 1989 to 2004. Data not available for 1999, 2001, 2003.

Source: Conservation Tillage Information Center, Purdue Univ., West Lafayette, IN.

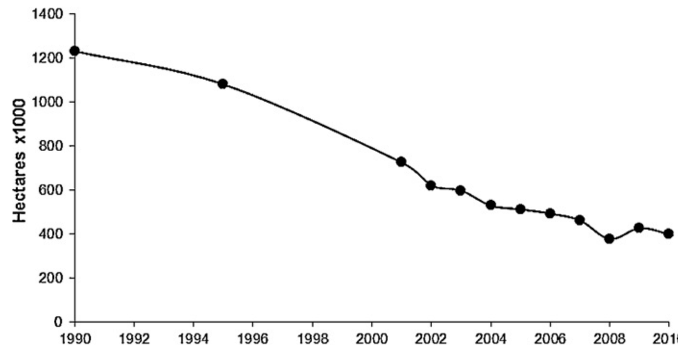

Fig. 4. Fallow land use in 25 counties from northeast Montana and northwest North Dakota from 1990 to 2010.

Source: United States Department of Agriculture – Farm Service Agency.

The adoption of no-till dryland cropping in the northern Great Plains has been accompanied by crop diversification and a reduction in fallow (Cochran et al., 2006). A change to continuous cropping has been common in areas where wheat–summer fallow was practiced previously. For instance, in northeast Montana and northwest North Dakota fallow decreased from 1.2 million hectares in 1990 to 0.4 million hectares in 2010 (Fig. 4). No-till has facilitated these changes due to greater snow capture from standing crop residue, reduced evaporative loss from the lack of tillage, low disturbance seed drills, and post-emergence herbicides (Aase and Siddoway, 1980; Aase and Reitz, 1989; Cochran et al., 2006).

Among the cropping systems in the northern Great Plains that have replaced wheat–summer fallow are rotations that include pulse and oilseed crops. Similar to the conditions in the Great Plains of Canada (Zentner et al., 2002), these rotations have been facilitated by adoption of no-till but also due to changes in crop markets, changes in government policy, and increased grower support through extension and research that drive crop diversification. Oilseed and pulse production in northeast Montana and northwest North Dakota combined for a total of 14% of production area in 2010. Initial production of oilseeds in this region increased at a more rapid rate than for pulse crops, where virtually no plantings were reported in 1990 (Fig. 5). However, oilseed production area in the region peaked in 2002, while pulse crop production area has steadily increased since 1990 and surpassed oilseed production area after 2008 (Fig. 5).

Management alternatives such as adoption of no-till in conjunction with annual cropping have provided favorable impact in the northern Great Plains. In a long-term study in northeast Montana initiated in 1984, Sainju et al. (2009) reported that a no-till annual cropping system for spring wheat reduced potential for soil

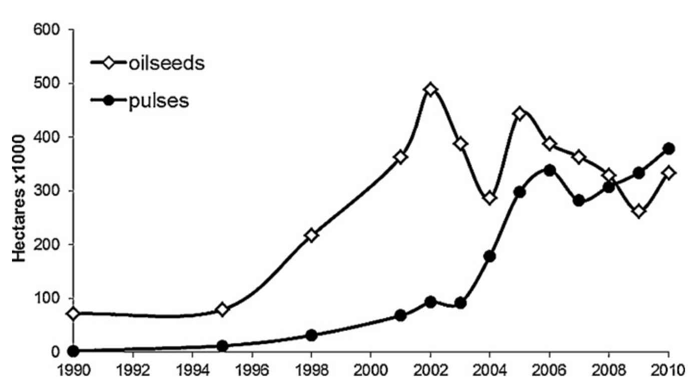

Fig. 5. Oilseed and pulse crop production area in 25 counties from northeast Montana and northeast North Dakota from 1990 to 2010.

Source: USDA – Farm Service Agency.

2. Adoption of no-till dryland cropping systems

2.1. Northern Great Plains

Adoption of dryland no-till management practices in the northern Great Plains has increased during the previous two decades. For example, a long-term survey conducted by the United States Department of Agriculture reported that no-till in small grain production in 25 counties from northeast Montana and northwest North Dakota increased from less than 5% of the total cultivated land area in 1989 to nearly 25% in 2004 (Fig. 3), representing 579,600 ha of no-till (CTIC, 2011). Estimates suggest that no-till adoption has continued to increase since 2004. For instance, local agency and extension personnel estimate that no-till in the northern Great Plains ranges from 50 to 90% among counties with an average of 60% (M. Friedrich, R. Bray, C. Hill, personal communication, 2011).

Table 1
Annualized grain and total biomass yield as affected by cropping systems averaged over climate and soil gradients and years (1986–1998) in eastern Colorado, USA (modified from Peterson and Westfall, 2004). The cropping systems are: 2-year = winter wheat–summer fallow; 3-year = winter wheat–corn–summer fallow; 4-year = winter wheat–corn–proso millet–summer fallow.

Variable	Cropping system (kg ha^{-1})				LSD (0.05)
	2-year	3-year	4-year	Continuous[a]	
Grain yield	1030	1770	1950		200
Total above-ground biomass	3100	4750	4760	5810	250

[a] The continuous system was compared with the other systems on a total biomass basis because it included forage crops that do not have a grain component.

erosion, improved soil quality, and increased soil organic matter compared to conventionally tilled spring wheat–summer fallow. No-till increases water use efficiency of spring wheat (Cutforth and McConkey, 1997), oilseeds (Cutforth et al., 2006), and pulse crops (Cutforth et al., 2002), underlying the contribution of no-till to the efficient use of soil water and precipitation in semi-arid environments. Cochran et al. (2000) found that total production of continuous spring wheat was about 25% greater than a spring wheat–summer fallow rotation in a long-term study in NE Montana initiated in 1984. Similar to conditions in southwestern Saskatchewan, pea (*Pisum sativum* L.) or lentil (*Lens culinaris* Medic) harvested for seed provided rotational benefits leading to increased wheat yield compared with continuous wheat in northern Montana (Miller et al., 2003b). Similarly, Allen et al. (2010) reported that continuous spring wheat grain yield was about 25% lower than yields in more diverse rotations that included pea.

2.2. Central Great Plains

Adoption of dryland no-till management practices in the central Great Plains has increased during the previous two decades. For example, a long-term survey conducted by the United States Department of Agriculture reported that no-till in northeast Colorado and southwest Nebraska increased from less than 5% of the cultivated land in the early 1990s to greater than 20% in recent years (CTIC, 2011; Fig. 3). The increased adoption of no-till is associated with the intensification of crop rotation from traditional winter wheat–summer fallow rotations. No-till crop rotations common in the central Great Plains are winter wheat–maize–summer fallow, winter wheat–maize–proso millet (*Panicum miliaceum* L.)–summer fallow, and continuous cropping without summer fallow [crops grown over the years included maize, sorghum, winter wheat, foxtail millet (*Setaria italica* (L.) P. Beauv.), and sunflower (*Helianthus annuus* L.)]. No-till is more commonly adopted with the more intensified crop rotations because, unlike the wheat–summer fallow rotation, the more intense crop rotations are able to utilize the increased soil water in no-till systems. Because dryland production of summer grain crops in rotation with wheat is primarily associated with no-till, available statistics on the production of dryland summer crops, such as maize, sorghum, sunflower, and millet, can be used as surrogate statistics for the adoption rate of no-till systems. In eastern Colorado, the dryland maize production increased from less than 10,000 ha in 1986 to 96,000 ha in 2010, reflecting a 10-fold increase. When considering other crops including sunflower and proso millet, summer crop production in no-till cropping systems has increased by about 208,000 ha in Colorado since 1986. Similarly, in the Nebraska Panhandle, dryland maize production went from just 2710 ha in 1991 to over 27,900 ha in 2001 (Lyon et al., 2004).

Intensifying the cropping systems using no-till has increased annualized grain yield by more than 75% relative to the yield of the winter wheat–fallow system (Peterson and Westfall, 2004) (Table 1). These yield increases have translated into 25–40% gains in net income for farmers (Kaan et al., 2002). The largest step gain in annualized yield was achieved with the addition of maize or sorghum to the system (two crops in 3-year system). Increasing cropping intensity to three crops in 4 years only resulted in small yield increases relative to the 3-year system. Adding diversity to intensified cropping systems has also shown promise for improving weed control in conservation tillage systems. Cropping intensification also has positive impacts on soil physical and chemical properties. Cropping system intensification under no-till management decreased bulk density of the surface soil layer, increased total porosity, and increased effective pore space (Shaver et al., 2002). The causal agent for the improvement in physical properties has been the addition of more crop residue biomass to the soil relative to the wheat–summer fallow system (Shaver et al., 2003). Coupled with minimal soil disturbance in a no-till environment, the additional residue C has promoted aggregation and has increased aggregate stability. This example demonstrates that higher net productivity associated with more intensive cropping can increase system sustainability.

2.3. Southern Great Plains

The adoption of conservation tillage, and particularly no-till, is much less in the southern Great Plains than in the lower PET climates of the central and northern Great Plains. For example, a long-term survey conducted by the U.S. Department of Agriculture showed that no-till is less than 5% of cultivated land area in northwest Texas and southwest Kansas (CTIC, 2011; Fig. 3). However, the long term survey infers tillage practices based on estimates of crop residue cover. In this region, it can be difficult to infer no-till adoption based on crop residue because some dryland crops do not produce enough residue to be classified as no-till in a visual residue survey. For example, under dryland conditions woody cotton residues provide only 37% of the cover achieved with the same mass of hollow stem wheat straw (Unger and Parker, 1976). In the southern Great Plains, the value of the wheat crop for winter grazing by cattle (*Bos taurus* L.) is frequently greater than the value of the grain. Low adoption rates of no-till in this region are related to reduced weight gain by cattle resulting from the slower crop growth in no-till versus conventional systems during the grazing period. Grazing winter forage with cattle also compacts the soil and many growers feel that tillage is required to alleviate the problem. Higher PET in the southern Great Plains also makes it more difficult to produce and retain sufficient crop residues to improve soil water storage efficiency compared to traditional systems involving inversion tillage. The gradient in PET over the Great Plains thus illustrates how adoption of no-till and other management practices vary depending on local conditions.

2.4. No-till alters the pest complex

As adoption of no-till has increased, there have been changes in the pest complex of wheat in the Great Plains. Many insects and diseases are harbored in crop residue from no-till systems and can affect subsequent crops. One example is the wheat stem sawfly, Cephus cinctus Norton (Hymenoptera: Cephidae), which is a key pest of wheat in the northern Great Plains of the United States

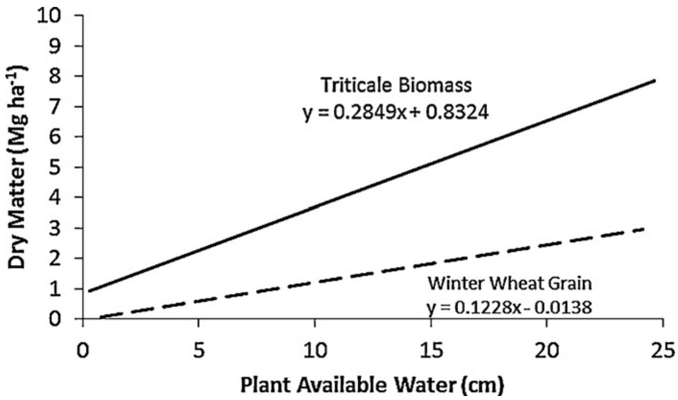

Fig. 6. Relationship between observed plant available water content measured at the time of planting and triticale biomass yield and winter wheat grain yield at Akron, Colorado.

Adapted from Nielsen et al. (1999, 2002), Nielsen and Vigil (2005).

Table 2

Correlation coefficients (r^2) for the relationship between soil water content at planting and dry matter and grain yields for the following crops with variable number of days to harvest: proso millet (*Panicum miliaceum* L.), pinto bean (*Phaseolus vulgaris* L.), sunflower (*Helianthus annuus* L.), grain sorghum (*Sorghum bicolor* L. Moench), and maize (*Zea maize* L).

Crop	Dry matter correlation	Grain yield correlation	Days to harvest
Proso	0.87	0.89	95
Pinto bean	0.82	0.84	95
Sunflower	–	0.65	116
Sorghum	0.80	−0.51	131
Maize	0.93	−0.64	148

Data from Lyon et al. (1995).

that has been clearly associated with no-till (Weaver et al., 2009). This pest has recently become a concern in the central Great Plains (Peairs et al., 2010) and it is speculated that the spread is associated with increasing no-till area. Similar observations have been made for crop diseases and weeds that have a competitive advantage in no-till environments. Managers will need to adapt to changes in pests and diseases as a result of increasing no-till production.

3. Research achievements in no-till dryland cropping systems

3.1. Informing crop and fallow choice with soil water and climate predictions

Although the climate of the Great Plains is classed as semi-arid, there are years when other climate types, from humid to arid, prevail (Thornthwaite, 1941). In years when humid or subhumid climates prevail, summer fallow is an unnecessary use of land and resources. However, in years when an arid climate prevails, summer fallow may make the difference between a profitable crop and no crop at all. The ability to discern when to use summer fallow and when to plant a crop would be beneficial in this highly variable climate. One approach to inform the decision is to quantify soil water at planting.

Soil water at planting time is a fairly simple measurement to collect. The ability to predict crop yields based on soil water at planting varies by crop and is affected by growing season precipitation. Available soil water at planting was strongly correlated with wheat yield (Fig. 6), with the response ranging from 39.7 to 282.9 kg ha^{-1} cm^{-1} (Nielsen et al., 1999, 2002; Nielsen and Vigil, 2005). The yield response to soil water increased with increasing precipitation during May and June. Lyon et al. (1995) noted a good correlation between soil water level at planting and aboveground biomass 12 weeks after planting for five summer crops, but the correlation with grain yield varied widely (Table 2). The best correlations with grain yield were associated with the crops of shortest duration (proso millet) and dry bean (*Phaseolus vulgaris* L.) and the poorest correlations were for the crops of longest duration (sunflower, grain sorghum, and maize). Dry matter accumulation of two annual forage crops (Fig. 6), spring triticale (× *Triticosecale* Wittmack;) and foxtail millet [*Setaria italica* (L.) P. Beauv.], increased linearly as available soil water at planting increased (Felter et al., 2006). This relationship was strongest during years of limited seasonal precipitation. Short-season summer crops were suggested for use in a dynamic cropping approach to reduce the frequency of summer fallow in the central Great Plains.

The ability to accurately forecast climate 3–6 months ahead of time could help farmers make better decisions, reduce unwanted impacts of fallow, and take advantage of expected favorable climate (Jones et al., 2000). However, there are many challenges associated with accurate, long-range climate forecasting. These challenges include understanding and communicating risk and uncertainty, applying forecasts over a range of scales, and the complexity of agricultural systems (Jones et al., 2000; Hammer et al., 2001).

Various groups have used the El Niño-southern oscillation phases (Jones et al., 2000; Hammer et al., 2001) or the related southern oscillation index phase system (Stone and Auliciems, 1992; Hammer et al., 1996) for long-range climate prediction with a goal to improve tactical management of crops. However, Lyon et al. (2003) did not show improved forecasting of summer rainfall in the central Great Plains using the southern oscillation index system. As the ability to accurately forecast climate 3–6 months into the future improves, it may be possible to combine knowledge of soil water content and climate forecasts to make tactical management decisions for crop production in the Great Plains. Until the skill of climate forecasts is adequate, however, growers may need to rely on knowledge of available soil water at planting and historic weather records, as demonstrated with dryland maize by Nielsen et al. (2010) to make tactical cropping decisions.

3.2. Alternative and fallow replacement crops

Alternative cropping systems in the Great Plains need to be identified to better manage limited production input resources, primarily plant-available water and N. The traditional wheat–summer fallow rotation has inefficient soil water and N utilization. Research has evaluated the potential of adding oilseed and pulse crops to the traditional wheat–summer fallow rotation to add diversity and improve efficiency. Drinkwater et al. (1998) suggested that inclusion of legumes in cropping systems increased the turnover and retention of soil N and organic carbon to improve ecosystem function and soil quality. In the central Great Plains, peas harvested for forage or grain have been grown successfully as fallow replacement crops. In the Canadian Great Plains, less water-intensive rotations have included pulse crops with great success (Karamanos et al., 2003; Miller et al., 2003a). For example, pea or lentil harvested for seed provided rotational benefits leading to increased wheat yield compared with continuous wheat (Miller et al., 2003b). Similarly, Allen et al. (2010) reported that continuous spring wheat grain yield in Montana was about 25% lower than yields in more diverse rotations that included pea.

In the northern Great Plains leguminous green manures have been utilized to reduce fertilizer N requirements (Pikul et al., 1997; Zentner et al., 2004; Miller et al., 2006). Potential benefits of green manures in place of fallow include reduced dependence on fossil fuel-derived fertilizer, soil quality improvement, and the potential to market crops as organic products. However, in dryland cropping, the tradeoff for the benefits of green manure crops is the soil water used to produce them and how the reduced water availability will affect the subsequent crop. Annual-legume species used for green manures have different water-use efficiencies and N_2-fixation capabilities. Lentil grown for green manure was identified as a suitable alternative to summer fallow in spring wheat–summer fallow cropping systems in northeast Montana (Pikul et al., 1997). Similarly, field pea served as a beneficial green manure crop in northern Montana (Miller et al., 2006). Biederbeck and Bouman (1994) reported that annual legumes that produced high quantities of biomass had higher water-use efficiencies than legumes that produced less biomass. When Indianhead lentil was grown in place of fallow in a spring wheat–summer fallow system in northeast Montana, Pikul et al. (1997) reported no differences in soil water content at wheat planting between the wheat–fallow system and the wheat–legume fallow system. While research on green manure crops has shown some success in the northern Great Plains, results of research for the higher PET central and southern Great Plains show that substituting legume production for a portion of the fallow period in a winter wheat–summer fallow system adversely affected subsequent wheat yields due to water use by the legume (Vigil and Nielsen, 1998; Nielsen and Vigil, 2005). These differing results demonstrate the importance of continued research to identify practices that could be more suitable for one environment over another.

Another potential change in dryland cropping systems that may improve production and sustainability is the inclusion of forage or biomass crops in the rotation. Recent research has shown that annual forage crop yields were highly correlated to starting soil water (Fig. 6) and could be a sensible choice if trying to decide between fallow and cropping because a reasonable estimate of yield could be made before planting based on soil water (Felter et al., 2006). Forage crops also grow for a shorter period of time than most grain crops, which leaves more time to store water in the soil for the subsequent winter wheat crop (Lyon et al., 2007). However, establishing consistent markets for forage products often limits the amount of dryland forage production. One market development that could lead to cropping shifts is the market for biomass in sustainable energy systems. As energy markets develop, the potential for inclusion of biomass crops in dryland regions could increase and expand no-till adoption. There is a need to balance the projected market needs for biomass with the need for crop residues to protect the soil and maintain productivity. For example, a recent study evaluated the potential for biomass production in dryland cropping systems in eastern Colorado. It was estimated that a dedicated, annual biomass crop could produce an average harvestable biomass of 5 Mg ha^{-1} year^{-1}, but that 2.5 Mg ha^{-1} year^{-1} were required to protect the soil from erosion and maintain soil organic carbon (Lloyd and Hansen, 2011).

There continues to be a need for improved soil water and nutrient management practices in the Great Plains. Oilseeds and especially pulse crops have shown promise to improve overall productivity and sustainability of the traditional spring wheat–summer fallow rotation. However, further research is required to better understand and facilitate the role of pulses, oilseeds, and developing crop alternatives into sustainable no-till cropping systems.

3.3. Mixed crop livestock systems

Livestock production, primarily cattle, plays an important role throughout the Great Plains. The importance of mixed crop–livestock systems with grazing of annual forages varies with climate conditions. As annual precipitation increases from 200 to above 500 mm, there is a corresponding production shift to less grazing and less production of drought tolerant crops, like sorghum, which are replaced by drought sensitive crops like maize (Schiere et al., 2006). Much of the Great Plains receives from 400 to 500 mm precipitation and is suited to combined production of drought tolerant crops and grazing cattle. For example, in the southern Great Plains, cattle commonly graze early vegetative growth of winter wheat grown with the dual purpose of producing forage and grain (Shroyer et al., 1993). This dual purpose cropping approach diversifies and intensifies the common wheat–sorghum–summer fallow crop rotation in the southern Great Plains.

Table 3
Wheat and sorghum grain yield in response to tillage and cattle grazing treatments in an experiment in Lubbock, Texas in the southern Great Plains. Grazing by tillage means within years followed by the same letter are not significantly different according to the Tukey honestly significant difference test.

Grazing–tillage treatment†	Grain yield (Mg ha^{-1})					
	2005	2006	2007	2008	2009	Mean
Wheat						
G–NT	2.07	–	1.93	0.88b	0.94	1.46
UG–SM	2.40	–	3.08	0.69b	0.82	1.75
UG–NT	2.74	–	2.94	1.63a	0.99	2.08
Sorghum						
G–SM	4.19	3.48	4.15	1.97b	1.63b	3.08
G–NT	4.48	3.50	4.34	1.95b	1.33b	3.12
UG–SM	4.18	3.65	3.99	1.91b	2.14b	3.17
UG–NT	4.28	4.02	4.26	3.27a	4.75a	4.12

Data from Baumhardt et al. (2011).
† G, grazed; UG, ungrazed; SM, stubble mulch tillage; NT, no-till.

The tradeoffs with dual-purpose crop livestock dryland systems are soil compaction from the cattle and the effects of compaction on crop growth and soil water. Most producers in the southern Great Plains who incorporate livestock grazing use stubble mulch tillage to alleviate surface soil compaction after grazing. Stubble mulch tillage uses wide blades that run below the soil surface to cut weeds and loosen the soil with minimal disturbance of residues on the soil surface. Suitability of grazing dryland, dual-purpose wheat in the wheat–sorghum–summer fallow rotation was evaluated by Baumhardt et al. (2009) using stubble-mulch tillage. They concluded that the dryland wheat–sorghum–summer fallow rotation produced sufficient wheat forage to permit grazing for 31 days without significantly decreasing mean yield of wheat grain that averaged 1.72 Mg ha^{-1} for ungrazed plots compared with 1.57 Mg ha^{-1} for grazed treatments. Similarly, the subsequent sorghum crop yields were unaffected by grazing, averaging 2.26 Mg ha^{-1} and 2.20 Mg ha^{-1} for the stubble-mulch tilled ungrazed and grazed plots. Limited grazing of dryland wheat successfully increased overall productivity of a stubble-mulch tilled wheat–sorghum–summer fallow crop rotation by adding the value of cattle grazing while maintaining wheat and sorghum grain yields.

Although stubble-mulch tillage during fallow may disrupt soil compaction due to grazing, there is a loss of soil water associated with the tillage operations. Water conservation with no-till management during fallow is superior to stubble-mulch tillage and may promote wheat establishment and early growth. The detrimental effects of grazing-induced compaction are potentially crucial in dryland production systems that rely totally on the rain infiltration process. In a study to quantify tillage and grazing effects in a wheat–sorghum–fallow rotation, observed wheat grain yield increased for no-till compared to stubble-mulch tillage by 0.47 Mg ha^{-1} in 2008 and 0.24 Mg ha^{-1} in 2009 ($p < 0.05$), but there were no significant tillage effects in 2005–2007. A significant tillage *x* grazing interaction was observed in 2008 (Table 3) that favored ungrazed no-till wheat over any grazed tillage combination (Baumhardt et al., 2011). The mean available soil water increased significantly ($p < 0.05$) from 118 mm for stubble-mulch to 139 mm with no-till in 2009, but in 2008 the corresponding soil water contents of 217 and 224 mm did not differ. In two of five years, the ungrazed no-till grain sorghum yield was significantly greater ($p < 0.05$) than all other tillage *x* grazing treatment combinations and exceeded the ungrazed stubble mulch tillage counterpart by 50–100%. In years with significant tillage by grazing interactions, the overall yield advantage without grazing for no-till generally exceeded the value of animal weight gain acquired with grazing. This illustrates the complex relationships in managing dryland cropping systems and how the potential value of early crop growth or crop residues for feed or other uses must be considered in light of the potential effects on subsequent crop productivity.

3.4. Runoff and soil erosion in dryland systems

Evaporation is responsible for the greatest amount of water loss in dryland cropping systems and management practices such as no-till have been adopted to reduce evaporative losses. Less is known about the magnitude of water loss due to runoff in dryland no-till systems. Summer precipitation in the Great Plains often comes as high intensity thunderstorms with potential to cause runoff. Research was conducted to assess runoff in dryland agroecosystems in the central Great Plains and the potential for improving precipitation use with management practices that reduce runoff. At study sites in eastern Colorado with average annual precipitation of 400 mm and 4% slopes, annual runoff ranged between 8 mm year^{-1} for no-till management with good surface protection to 80 mm year^{-1} for no-till management with poor protection of the soil surface (Norvell et al., 2008). The no-till scenarios with poor surface protection conditions were caused by multi-year drought conditions that resulted in low quantities of crop residue. Because no-till surfaces lack roughness and can experience soil compaction, they can be vulnerable to runoff when residue cover is low. Long term modeling of no-till dryland cropping systems in eastern Colorado showed average runoff losses of 29 mm year^{-1} for a no-till winter wheat–maize–summer fallow system and 32 mm year^{-1} for a tilled winter wheat–summer fallow system. Although differences in runoff were small, the associated soil water erosion rates were significantly less than for no-till (0.6 Mg ha^{-1} year^{-1}) than for the traditional wheat–summer fallow rotation (1.6 Mg ha^{-1} year^{-1}).

In the Great Plains, wind erosion is generally more severe than water erosion and no-till is an effective management approach at reducing wind erosion. Wind erosion in the Great Plains is reported to be greater than 6 Mg ha^{-1} year^{-1}, with some areas being as high as 18 Mg ha^{-1} year^{-1} (USDA-NRCS, 2000). A recent modeling study showed that no-till dryland cropping systems had lower erosion rates at sites in the central Great Plains. In northeast Colorado, wind erosion from a no-till wheat–maize–summer fallow rotation averaged 5.2 Mg ha^{-1} year^{-1}. However, the same cropping system at a site in southern Colorado with similar precipitation but higher PET had an annual erosion rate of 8.1 Mg ha^{-1} year^{-1}. The crop residue levels at these sites averaged 4.9 and 2.8 Mg ha^{-1}, respectively. These observations illustrate that no-till is effective at protecting against wind erosion in regions where there is adequate residue production, but where residue production is limited, management practices other than no-till are needed to control wind erosion. This partially explains the reduced level of no-till adoption in the southern Great Plains (Fig. 3), where tillage is often used to create ridges to protect against wind erosion due to low residue cover.

4. Summary

The semiarid U.S. Great Plains are a major production region for dryland wheat, with spring wheat as the dominant crop in the northern region and winter wheat in the central and southern regions. The traditional production system is a wheat–summer fallow rotation with conventional or stubble mulch tillage. No-till systems are being adopted together with more intensive crop rotations that reduce fallow frequency, increase precipitation use efficiency, reduce erosion, and improve soil properties. No-till adoption is greatest in the northern region of the Great Plains, where climate conditions are favorable for intensified, no-till crop rotations. Greater than 25% of cultivated land in the northern Great Plains is managed with no-till and adoption continues to increase. Inclusion of oilseed crops in continuous crop rotations without fallow is common. In the central Great Plains, about 20% of cultivated land is managed with no-till systems. In this area, no-till is generally associated with a 3-year rotation of winter wheat–summer crop–summer fallow (typical summer crops are maize, sorghum, sunflower, proso millet). There is much less adoption of no-till in the southern Great Plains, where production levels often fail to produce adequate crop residue to realize the benefits of no-till. In this region, tillage is often used to alleviate compaction from livestock grazing or to roughen the surface as a protection against wind erosion. However, some producers are adopting no-till systems and research suggests that potential crop yield advantages for no-till in the southern Great Plains may be of greater economic value than the value currently gained by grazing in the tilled systems.

A major decision for dryland farmers in the Great Plains is whether to fallow or plant a crop. Research has evaluated relationships between stored soil moisture levels at the time of planting and the resulting crop yield as a tool to assist farmers with this decision. The relationships are useful, but they are best for crops with relatively short growing seasons. On-going research seeks to couple long-range weather forecasting with soil moisture assessments to improve the predicted yield potential for other crops.

Alternative no-till crops and crop rotations are being evaluated for the potential to increase precipitation use efficiency, improve soil properties, reduced dependence on N fertilizers, adapt to climate change, and for develop alternative markets. Inclusion of pulses as green manures is of interest, but the potential benefits of these crops must be weighed together with the use of already limited water resources. Inclusion of annual forage crops can improve precipitation use efficiency and resilience to climate change in the Great Plains and these crops may help meet emerging markets for biomass based renewable energy. Sustaining crop production in the Great Plains is highly dependent on reducing soil erosion, maintaining soil organic matter, and economic profitability. No-till based systems will continue to play an important role in the sustainability of dryland cropping in the Great Plains, but managers will need to adapt to changes in pests and diseases as a result of increasing no-till production.

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