Incorporating annual legumes (pulses) into cropping systems of the southern Great Plains (SGP) could provide producers with a variety of services including summer forage, biological N, or new grain crops. A number of pulse species and cultivars could be incorporated into these cropping systems, but producers will require knowledge and good management skills to ensure successful application of these practices. Critical knowledge gaps related to the effect of climate of the region on pulse crops exist, including low and variable precipitation, high temperatures, and winds associated with the dry summer months. Such climatic conditions can also create erosion problems on lands used to produce cool-season cereals. Incorporating pulses into the rotation as cover crops could help reduce erosion and increase soil organic matter during the traditional fallow period, thus helping to improve overall soil quality (Biederbeck et al., 1993).

Double-cropping of winter wheat (*Triticum aestivum* L.) and soybean (*Glycine max* (L.) Merr.) is an important agronomic practice in many U.S. regions (Carlson and Marra, 1986), because this practice often increases economic returns compared to mono-crop systems (Crabtree et al., 1987; Sanford et al., 1986). The ability of legumes to fix atmospheric N that could be used by subsequent grain crops has stimulated interest in pulse crops as forage or green manure (Rao et al., 2005), particularly with highly volatile fertilizer costs.

Growing warm-season legumes during fallow periods associated with traditional continuous systems of winter wheat (*Triticum aestivum* L.) in the southern Great Plains (SGP) can provide supplemental forage, biological N, and protection from soil erosion, provided the legumes can tolerate drought stress and not deplete the available water in the soil profile. Our objective was to quantify water use by five species of pulse legumes (pigeon pea [*Cajanus Cajan* (L.) Millsp.] cv. GA-2, guar [*Cyamopsis tetragonoloba* (L.) Taub., cv. Kinman], cowpea [*Vigna unguiculata* (L.) Walp., cv. Chinese red], mung bean [*Vigna radiate* (L.) Wilcz., cv. Berkins], and soybean [*Glycine max* (L.) Merr., cv. Hutcheson (the control)])

Seeds were inoculated and planted after wheat harvest in mid-June 2003 through 2006. The amount of water in the upper 65 cm of the soil profile was measured on nine dates [from 45 d before planting legumes to 195 d since planting (DSP)]. Significant ($P < 0.01$) differences in soil water were recorded among treatments, dates, and years. Differences in soil water among fallow, cowpea, and mung bean were less following the 2003 and 2004 summer seasons and most noticeable in 2005 and 2006. Mung bean, guar, soybean, and pigeon pea used the greatest amounts of water in 2005, the wettest season, while cowpea and mung bean used the least in 2003. Mung bean, cowpea, and guar generated smaller water deficits and used less soil water, in three of four years, and could be effective in wheat-summer legume rotations in the SGP.

**ABSTRACT**

Growing warm-season legumes during fallow periods associated with traditional continuous systems of winter wheat (*Triticum aestivum* L.) in the southern Great Plains (SGP) can provide supplemental forage, biological N, and protection from soil erosion, provided the legumes can tolerate drought stress and not deplete the available water in the soil profile. Our objective was to quantify water use by five species of pulse legumes (pigeon pea [*Cajanus Cajan* (L.) Millsp.] cv. GA-2, guar [*Cyamopsis tetragonoloba* (L.) Taub., cv. Kinman], cowpea [*Vigna unguiculata* (L.) Walp., cv. Chinese red], mung bean [*Vigna radiate* (L.) Wilcz., cv. Berkins], and soybean [*Glycine max* (L.) Merr., cv. Hutcheson (the control)])

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**Abbreviations:** DSP, date since planting; FWUE, field water use efficiency; MG, maturity groups; NWUE, nitrogen water use efficiency; SGP, southern Great Plains.

**Incorporating annual legumes (pulses) into cropping systems of the southern Great Plains (SGP) could provide producers with a variety of services including summer forage, biological N, or new grain crops. A number of pulse species and cultivars could be incorporated into these cropping systems, but producers will require knowledge and good management skills to ensure successful application of these practices. Critical knowledge gaps related to the effect of climate of the region on pulse crops exist, including low and variable precipitation, high temperatures, and winds associated with the dry summer months. Such climatic conditions can also create erosion problems on lands used to produce cool-season cereals. Incorporating pulses into the rotation as cover crops could help reduce erosion and increase soil organic matter during the traditional fallow period, thus helping to improve overall soil quality (Biederbeck et al., 1993).

Double-cropping of winter wheat (*Triticum aestivum* L.) and soybean (*Glycine max* (L.) Merr.) is an important agronomic practice in many U.S. regions (Carlson and Marra, 1986), because this practice often increases economic returns compared to mono-crop systems (Crabtree et al., 1987; Sanford et al., 1986). The ability of legumes to fix atmospheric N that could be used by subsequent grain crops has stimulated interest in pulse crops as forage or green manure (Rao et al., 2005), particularly with highly volatile fertilizer costs.


doi: 10.2135/cropsci2009.03.0134

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For example, the cost of N fertilizer (dry urea) in central Oklahoma between March and September 2008 for dual-purpose (grazing and grain production) wheat averaged $175 (±$35) ha⁻¹ compared to $56 ha⁻¹ in 2004 through 2005 (B. Northup, unpublished data). However, legumes are not commonly double-cropped with cereal grains in rain-fed production systems of the drought-prone SGP due to depletion of soil water (Brown, 1964).

Available information on water use by most legume species in the SGP is limited, but needed to effectively double-crop legumes with wheat. Water use, water use-efficiency, and depletion of soil water differ among plant species and cultivars, and growing seasons. Rao and Northup (2008) reported 2.0 to 2.5 times more water use by soybean during wet years than in dry years in the SGP. In other regions, indeterminate cultivars of soybean used more soil water than corn (Zea mays L.) during the growing season in India (Bargava et al., 1976). Specht et al. (1986) observed differences among soybean cultivars in response to a seasonal water gradient in Nebraska. They also reported that some cultivars were less sensitive to dry conditions, while others performed better with irrigation. These results indicate water use by annual warm-season legumes is variable, there could be substantial differences in plant growth and development, and some species could be functional components of agricultural systems in the SGP.

The capacity of pulse crops to supply forage, grain, or biological N has resulted in an increased interest in incorporating annual legumes into current cropping systems of the SGP. This study was conducted to determine the amount of water used and the water use-efficiency of various pulse crops during the summer fallow period associated with winter wheat production in a continuous no-till system. It was a component of a larger study on the potential roles of pulse legumes in agricultural systems of the SGP (Rao and Northup, 2009).

**MATERIALS AND METHODS**

**Study Site**

This study was conducted at the USDA-ARS Grazinglands Research Laboratory (35°40′ N, 98°00′ W, elevation 414 masl) near El Reno, OK. Annual legumes were grown during the traditional fallow period (June through October) associated with continuous no-till winter wheat in 2003 through 2006. The predominant soil series was a Brewer silty clay loam (mixed, superactive, thermic udertic argiustolls), moderately well drained with 0 to 1% slope, low permeability (2 to 15 mm h⁻¹), and a pH of 6.9 (USDA-NRCS, 1999). Average minimum and maximum temperatures during June through October were 15° and 29°C, respectively. Amount and distribution of precipitation during the study period varied within and among years (Table 1). Growing season (June through October) precipitation in 2003 through 2006 was 74, 89, 114, and 43% of the long-term (1971 through 2000) average (425 mm). Therefore, the study was undertaken during a drought period.

**Experimental Design**

Cultivars of four pulse legumes were included in the study: pigeon pea [Cajanus Cajan (L.) Millsp.] (cv. GA-2), guar [Cymopsis tetragonoloba (L.) Taub.] (cv. Kinman), cowpea [Vigna unguiculata (L.) Walp.] (cv. Chinese red), and mung bean [Vigna radiate (L.) Wilcz. (cv. Berkins)]. Soybean (cv. Hutcheson) was included as a control, to describe the effect of the most common legume for this region. The legumes varied in length of growing season and maturity groups (MG). The cultivars were selected on the basis of adaptation to dry conditions, differences in timing of peak production, and some degree of historical use in the region (e.g., guar, cowpea, and mung bean). Cowpea and mung bean were considered “short-growing season species,” while guar and pigeon pea were considered “long-growing season species.” The control (Hutcheson soybean) belonged to MG V. Phosphorus was applied at recommended rates for legumes (26 kg ha⁻¹) following grain harvest of no-till winter wheat (15–20 June), though type of fertilizer was changed from 0–46–0 (N–P₂O₅–K₂O) to 18–46–0 (N–P₂O₅–K₂O) in 2005 and 2006, when the former fertilizer was unavailable. This resulted in a small amount of pre-plant N applied to plots during the latter two years (25 kg ha⁻¹). Seeds of each cultivar were treated with appropriate inoculants (Bradyrhizobium japonicum for soybean, cowpea-type Rhizobium spp. for guar, mung bean, cowpea, and pigeon pea; Nitratin Inc., Milwaukee, WI) and planted 2 cm deep in 60-cm spaced rows (15–20 June of each year). Treatments were replicated three times in 3 × 20 m plots. Cultivars were planted on the same plots throughout the study so that treatments were repeated in space. Seeding rates were varied to achieve a uniform 10 seeds m⁻¹ of row length for each species. Access tubes (1.2 m in length) for a neutron probe (Campbell Pacific Nuclear International, model 503 DR, Martinez, CA) were installed near the center of two replicate plots per cultivar with a hydraulic soil probe.

**Data Collection**

Herbage was clipped at a height of 2.5 cm from three, randomly selected 0.5-m row lengths at the end of the growing season for each species. Samples were dried in a forced-draft oven at 65°C to a constant weight (approximately 60 h), and weighed to calculate total aboveground biomass. The samples were then ground to a 1 mm particle size for laboratory analyses. Samples were analyzed for N concentration with a complete-combustion N analyzer (Leco 1000, Leco Corp., St. Joseph, MI). Nitrogen accumulated (Kg N ha⁻¹) by the different species was calculated by multiplying N concentration with amount of biomass. Rainfall and ambient temperature were monitored at the experimental site. Soil water (mm⁻¹ depth increment) was measured at different times of the year (±3 d) on plots planted to legumes, and replicate (n = 3) summer fallow plots. Dates included 26 April (initiation of flowering by wheat), 12 June (wheat harvest and legume planting [0 d since planting (DSP)]), 2 and 15 August (45 and 60 DSP), 1 and 15 September (75 and 90 DSP), and 2 and 16 October (105 and 120 DSP, corresponding to end of pulse season and planting date for wheat), and in late-December (190 DSP), to correspond to end of fall growing season for wheat. Soil moisture was measured in 0 to 20-, 20 to 35-, 35 to 50-, and 50 to 65-cm depth increments. The neutron probe was calibrated in...
situ at Bushland, TX as described by Evett and Steiner (1995), and calibration equations were developed for the A and B horizons of the soils encountered on the study site (Gardner, 1986). Total water use by each species was calculated by subtracting the amounts of soil water at harvest from that at planting, and adding precipitation received during the growing season. While water loss through deep percolation and evaporation existed, they were not enumerated in our calculations. Deep percolation was considered negligible because of the prevailing temperature and precipitation patterns. Runoff was negligible due to the flat topography of the area. Field water use efficiency (FWUE), and nitrogen water use efficiency (NWUE) of each species was calculated as the ratio between peak biomass (or accumulated N) at the end of the growing season (see Rao and Northup, 2009) and total amount of water (mm) lost from the profile (soil water plus precipitation) during the growing season via transpiration and evaporation (Brown, 1999).

Statistical Analyses
Amount of available soil water was analyzed by depth increment as a double-repeated measure in cross-sectional (time series) analyses. Sampling dates and years were the cross-sectional elements, and were analyzed with unstructured variance/covariance matrices (Littell et al., 1996; Patetta, 2005). Unstructured matrices were used in the model due to uneven spacing of sampling dates, change in level of covariance among sampling dates, and autocorrelation among sampling dates and years. The different legumes and fallow treatments were analyzed as fixed effects, as were their interactions with the repeated elements.

End of season differences in soil water compared to summer fallow, total soil water used, FWUE, and NWUE were analyzed by mixed models, with species the main fixed effect and year the fallow, total soil water used, FWUE, and NWUE were analyzed effects, as were their interactions with the repeated elements.

RESULTS
Aboveground Biomass
The greatest amount of biomass (Table 2) was generated by soybean during 2005 (10,011 kg ha\(^{-1}\)), with the second highest production generated by pigeon pea in 2005 (7479 kg ha\(^{-1}\)) and guar in 2004 (7422 kg ha\(^{-1}\)). Mung bean, cowpea, and guar produced the lowest amounts of biomass during 2003 (2819, 2026, and 2956 kg ha\(^{-1}\), respectively). The most productive year for the short-season species (cowpea, mung bean) and guar was 2004, while pigeon pea and soybean were most productive during 2005. More detailed descriptions of biomass responses by these pulse crops can be found in Rao and Northup (2009).

Soil Water
Significant \( (P < 0.01) \) interactions were recorded in amounts of soil water between legume species and fallow treatments, sampling date, and years for all four depths (Fig. 1 and 2). The three-way interactions were primarily caused by variability in soil water among the four years of the study, with general declines recorded in 2004 and 2005 beneath soybean compared to summer fallow. Large variations in soil water were also recorded in response to rainfall events during 2003 through 2005, particularly in the uppermost layers. Most rain events received during the study lacked the volume to penetrate to the deeper sections of the soil profile. There was little difference in available soil water at the end of growing seasons for the legumes (120 DSP) in the upper three soil layers. Profile differences between the short-season (cowpea and mung bean) legumes and fallow conditions, and within the top two layers under long-season legumes (pigeon pea, guar, and soybean) or fallow conditions during 2003 and 2004 were negligible. The amounts of soil water in legume-treated plots in December (190 DSP) in 2003 and 2004 (after wheat planting) as similar to that recorded at the end of the summer growing seasons. In contrast, differences in available soil water measured for fallowed plots and those planted to legumes in 2005 and 2006 were significant.

There were small differences in soil profiles water content between fallow and the two short-season legumes at the end of the 2003 and 2004 summer growing seasons, and guar in 2004 (Fig. 3). However, soil water content for the legume-treated plots was similar to fallow-treated plots by end of fall growing season of wheat (195 DSP) in 2003 and 2004. Differences between fallow and legume treated plots were most noticeable in 2005 and 2006, with

### Table 1. Monthly summer and pre- and post-growing season precipitation during 2003 through 2006, and 30-yr (1971–2000) averages.

<table>
<thead>
<tr>
<th>Month</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>30-yr avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar–May</td>
<td>134</td>
<td>132</td>
<td>110</td>
<td>172</td>
<td>295</td>
</tr>
<tr>
<td>Jun</td>
<td>17</td>
<td>52</td>
<td>117</td>
<td>41</td>
<td>125</td>
</tr>
<tr>
<td>Jul</td>
<td>142</td>
<td>82</td>
<td>90</td>
<td>40</td>
<td>67</td>
</tr>
<tr>
<td>Aug</td>
<td>63</td>
<td>88</td>
<td>144</td>
<td>75</td>
<td>69</td>
</tr>
<tr>
<td>Sep</td>
<td>27</td>
<td>36</td>
<td>103</td>
<td>22</td>
<td>87</td>
</tr>
<tr>
<td>Oct</td>
<td>67</td>
<td>120</td>
<td>31</td>
<td>6</td>
<td>77</td>
</tr>
<tr>
<td>Nov–Dec</td>
<td>46</td>
<td>142</td>
<td>5</td>
<td>70</td>
<td>87</td>
</tr>
<tr>
<td>Total</td>
<td>496</td>
<td>652</td>
<td>500</td>
<td>426</td>
<td>807</td>
</tr>
</tbody>
</table>

### Table 2. Total (herbage, pods, and grain) aboveground biomass (± 1 s.e.) produced by five species of pulse crops during the 2003 through 2006 growing seasons.

<table>
<thead>
<tr>
<th>Species</th>
<th>2003 (± s.e.)</th>
<th>2004 (± s.e.)</th>
<th>2005 (± s.e.)</th>
<th>2006 (± s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cowpea</td>
<td>2026 (111)</td>
<td>4838 (570)</td>
<td>3216 (126)</td>
<td>3291 (140)</td>
</tr>
<tr>
<td>Mung Bean</td>
<td>2819 (780)</td>
<td>5949 (475)</td>
<td>3055 (430)</td>
<td>4554 (783)</td>
</tr>
<tr>
<td>Guar</td>
<td>2956 (114)</td>
<td>7422 (102)</td>
<td>4822 (100)</td>
<td>4393 (738)</td>
</tr>
<tr>
<td>Pigeon pea</td>
<td>3932 (630)</td>
<td>6447 (205)</td>
<td>7471 (995)</td>
<td>4847 (1453)</td>
</tr>
<tr>
<td>Soybean</td>
<td>3619 (832)</td>
<td>5938 (543)</td>
<td>10011 (2841)</td>
<td>2746 (2745)</td>
</tr>
</tbody>
</table>
little recovery, except for guar and cowpea treatments in 2005, by the end of summer, or by December.

**Water Use and Water Use Efficiency**
Species × year interactions in difference between soil water present under summer fallow and the five legume species were significant ($F_{12,20} = 5.8; P < 0.01$). The largest differences (compared to fallow) were recorded for pigeon pea soybean and guar during 2005 and 2006 (Fig. 4, top panel). The smallest deficits developed under cowpea and mung bean during 2003 and 2004, and guar in 2004. The short-season species generally developed smaller differences in soil water compared to fallow conditions across all years, except 2006.

Year ($F_{4,35} = 500; P < 0.01$) effects on FWUE were significant, but species effects ($F_{3,29} = 0.6, P = 0.30$) and species × year interactions ($F_{12,20} = 1.0; P = 0.41$) were not significant. Overall FWUE (±1 s.e.) of the five species was 19.6 (±2.8) kg ha⁻¹ mm⁻¹ soil water, while FWUE of 26.3 (±2.3), 18.5 (±1.1), 12.9 (±1.9), and 20.9 (±1.9) kg ha⁻¹ mm⁻¹ were recorded in 2003, 2004, 2005, and 2006, respectively (LSD = 1.9). None of the main effects related to year ($F_{3,20} = 2.1; P = 0.13$), species ($F_{4,22} = 2.2; P = 0.10$), or their interactions ($F_{11,20} = 1.7; P = 0.15$) on nitrogen WUE were significant. Overall NWUE (±1 s.e) was 0.24 (±0.02) kg N ha⁻¹ mm⁻¹.

**DISCUSSION**
Differences in soil profile water content for plots planted to summer legumes and the fallow treatment became detectable four to six weeks after planting. The most noticeable level of water use occurred in August through September, as the legumes matured and air temperatures increased. Similar results were reported for other soybean studies (FAO-AGL, 2002). The effect of double-cropping legumes on soil water in this study appeared different from a study in central Oklahoma on the effects of double-cropping soybean after winter wheat on infiltration. Daniel et al. (2006) found that soybean grown under conservation tillage practices during the summer reduced runoff volume by 50% and lengthened time to initial runoff by 45% following simulated rainfall events. The root systems of soybean were thought to provide pores in the soil profile that allowed rapid initial infiltration of water. Though infiltration may be improved, it might...
not result in a net increase in soil water. Warm-season legumes will use available water to produce biomass, so net increases in soil water may not occur. For example, Rao and Northup (2008) recorded more soil water beneath soybean cultivars during the driest of three years, but 2.0 to 2.5 times higher water use during two years with roughly “average” growing conditions.

Some cumulative effects of double-cropping legumes (compared to summer fallow) after winter wheat were noted during the latter years of this study. Although some recharge occurred before planting the pulse crops in summer or wheat in the fall, less soil water was present deeper in the profile during and after the 2005 and 2006 growing seasons. Precipitation during the fall and winter lacked the volume required to fully recharge the soil profile before planting the legumes. Wheat producers in the SGP rely on this water to ensure good stand development for subsequent grain production (Lindstrom et al., 1976). As such, double-cropping pulses during the traditional fallow period under dry conditions could have negative economic effects (Redmon et al., 1995) unless the legume fixes enough N or generates enough seed yield to offset potential losses in the subsequent wheat crop. Rao et al. (2005) reported that forage soybean in the study area was capable of capturing 85 kg N ha⁻¹ in plant tissues, depending on growing season. The five legumes in this study were capable of fixing 48 to 157 kg N ha⁻¹ in above ground biomass (Rao and Northup, 2009). Further research is required to determine if tradeoffs between losses of wheat grain and N captures or grain values from double-cropped legumes are viable.

The legume species reduced amounts of available soil water over the growing seasons, but there was little difference between the fallow and legume plots at end of summer in 2003 and 2004, particularly the short-season species (mung bean and cowpea). The most notable difference was recorded during 2006, which was the driest and final season of this study. Overall, our responses indicate warm-season legumes can be grown during the fallow period of continuous winter wheat for a limited series of years—assuming adequate rainfall—without causing large reductions in available soil water for wheat crops. However, pulses may still be difficult to incorporate into cropping systems of the SGP, given the tendency toward drought. The best use of warm-season legumes would be as a tactical tool, applied during growing seasons with normal or higher precipitation, so that water requirements of both wheat and the pulse crop could be met. This approach may be difficult to implement, given the current shortcomings and inaccuracies in climate forecasts for the SGP (Schneider and Garbrecht, 2003).

There was no identifiable effect on FWUE related to legume species, as all species generated similar levels of biomass per unit of soil water (i.e., 19.6 ± 1.1 kg ha⁻¹ mm⁻¹). Nitrogen WUE of the legumes species was also similar (i.e., 0.24 ± 0.02 kg ha⁻¹ mm⁻¹). Variation in species responses to the diverse growing conditions during this study likely contributed to the lack of difference. For example, growing conditions during the wettest and driest growing seasons (2005 and 2006, respectively) resulted in similar FWUE. This was not an unexpected result, as many species tend to have high variability in response to growing conditions and can show interactions between growth stage and environment. A range of guar cultivars exhibited high levels of variation in production to conditions across a range of sites in the southern Plains, and annually within a site (Stafford, 1982). Water use efficiency in cowpea was higher under drought conditions in the vegetative stage, but was reduced when drought occurred during the flowering

![Figure 3. Changes in soil water (±1 s.e.) generated by five pulse crops during the 2003 through 2006 growing seasons, compared to fallow conditions. The dashed lines (0 ± 1 s.d.) represent the mean (53.6 ± 7 mm) amount of soil water present under fallow conditions.](Image)
stages (Turk and Hall, 1980). Further, biomass produced by different cultivars of cowpea, mung bean, and soybean grown in north-central Texas varied significantly during years with different amounts and patterns of precipitation (Muir, 2002; Muir et al., 2008). Rao and Northup (2008) recorded variations in water use efficiencies of different cultivars of forage soybean during a series of normal to dry growing seasons. As such, growing conditions during individual years can be as important as the genetic potential of a species to be productive under drought. Water use efficiency may therefore not be the best measure of effective water use for legumes double-cropped with winter wheat, since they utilize soil water on the basis of availability. All the legumes included in this study efficiently produced biomass on limited amounts of water during dry years. However, this efficiency did not carry-over to years with normal or wetter growing conditions.

A better measure of the functionality of annual legumes double-cropped with wheat in dry land systems might be the water deficit created, as this deficit must be overcome to grow a subsequent wheat crop. Though FWUE was not different among species, there were differences in water deficits and amounts of soil water used to generate biomass. Cowpea and mung bean had short seasons of growth, and had matured by early September. These shorter growing seasons allowed soil moisture received in September and October to be conserved, compared to the longer growing season required by the other species.

**CONCLUSIONS**

Identifying the most water-efficient pulse legume, based on FWUE, for use during summer fallow of continuous wheat in the SGP was not possible. Any of the tested species could be incorporated into farming systems. However, mung bean, cowpea, and guar generated lower water deficits in three of four years, utilized less soil water in two of four years, and would therefore be more effective as part of a wheat-summer legume rotation in the SGP. The usefulness of these legumes will depend on factors related to timing of farming operations, length of available growing season, growing conditions, and nutrient requirements for a following crop. Prolonged dry periods are regular occurrences in the SGP, and current models used to predict precipitation at the growing season scale are unreliable. Given the importance of wheat production in the SGP, and the frequent occurrence of drought, double-cropping annual pulse legumes with winter wheat should be considered a short-term tactical tool, and be restricted to years when precipitation allows optimum production from both the legume and wheat. Short duration legumes that mature earlier may be an option if fall forage produced by winter wheat is required for grazing, as precipitation received after maturity can be utilized by winter wheat. If wheat is grown specifically for a grain crop, wheat seeding may be delayed until the long-season legumes mature. Alternatively, a multi-crop rotation including wheat (fall through spring), summer legume, winter fallow, and short-season spring forage or grain crops could be developed to conserve moisture, improve soil condition, and help diversify farming operations and income in the SGP (Allen et al., 2007; Franzluebbers, 2007; Kirschenmann, 2007).

**Acknowledgments**

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**References**


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