Forage and Grain Soybean Effects on Soil Water Content and Use Efficiency

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ABSTRACT
Growing legumes in the southern Great Plains (SGP) during fallow periods between wheat (*Triticum aestivum* L.) crops can protect soil, add N to soil, and supply high-quality summer forage. This study determined the water used, water use efficiency (WUE), and soil water depletion of forage (*n* = 3) and grain (*n* = 1) soybean (*Glycine max* (L.) Merr.) cultivars on silt loam soils following winter wheat harvest during the 2003 to 2005 summer growing seasons. Interactions (*P* < 0.01) in soil water content occurred between sampling date, cultivars, and years. More soil water was recorded under soybean in 2003 than 2004 or 2005, but was lower than in fallow plots. Year effects (*P* < 0.05) were recorded for standing crop, water used, and WUE. While cultivar effects were not significant (*P* > 0.10). All cultivars used 2.0 to 2.5 times more water in 2004 and 2005 than 2003 (driest year). Forage production in 2003 (3034 kg ha$^{-1}$) was 55% lower than in 2004 and 2005. Higher WUE (kg ha$^{-1}$ mm$^{-1}$) was recorded in 2004 (16.0) than 2003 (13.2) or 2005 (10.9). Incorporating soybean into fallow periods following wheat generally limits the amount of soil water available for fall production of wheat forage in the SGP.

USDA-ARS, Grazinglands Research Lab., 7207 W. Cheyenne St., El Reno, OK 73036. Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by USDA and does not imply its approval to the exclusion of other products that may be suitable. Received 1 Aug. 2007. *Corresponding author (Srinivas.rao@ars.usda.gov).

Abbreviations: DAS, days after seeding; SGP, southern Great Plains; WUE, water use efficiency.

The summer growing season in the southern Great Plains (SGP) is characterized by a combination of low precipitation, high temperatures, and high winds. Such conditions can create erosion problems on lands used for production of cereal crops. One possible solution is to incorporate legumes as a cover crop during the summer fallow period (June to October). Such a planting would help limit soil erosion, provide organic matter, and fix N to maintain soil quality (Biederbeck et al., 1998). Warm-season legumes could also be used as a source of high-quality summer forage for livestock production.

Double-cropping wheat and soybean is an important agronomic practice in several regions of the United States. Carlson and Marra (1986) reported that nearly one-third of the total soybean acreage in the southeast is double cropped with wheat. Double-cropping wheat (*Triticum aestivum* L.) and soybean (*Glycine max* (L.) Merr.) usually gives greater economic returns than mono crop systems (Crabtree et al., 1987; Sanford et al., 1986). However, legumes are not commonly used in grain production systems of the SGP, despite their potential advantages. Brown (1964) described extensive depletion of soil water as a major reason for excluding legumes from cereal rotations in this drought prone region. However water use, water use efficiency...
(WUE), and soil water depletion varies among species and cultivars. Hattendorf et al. (1988) reported mean daily water use of sunflower (Helianthus annuus L.) at 22% greater than rates for corn (Zea mays L.), grain sorghum [Sorghum bicolor (L.) Moench], pearl millet [Pennisetum americanus (L.) Leecke], or soybean. Indeterminate soybean cultivars used more soil water than corn by the end of the growing season (Bargava et al., 1976). Specht et al. (1986) observed differences among soybean cultivars in response to a seasonal water gradient and found some cultivars were less sensitive to drought while others performed better under irrigation.

Information on water requirements of legumes, particularly in combination with other crops, is necessary to understand the effect of including soybeans in double-cropping systems. Information on such basic agronomic characteristics of soybean in the SGP requires definition. The objective of this study was to determine the amount of water used and WUE of forage and grain-type soybean cultivars, and their effects on soil water content during the summer growing season, in a production system with continuous no-till winter wheat.

**MATERIALS AND METHODS**

**Study Site**

Experiments were conducted during June through October of 2003, 2004, and 2005 at the USDA-ARS Grazinglands Research Laboratory (35°40' N, 98°00' W, elevation 414 m) near El Reno, OK. Soil on the experimental site was a Brewer silty clay loam (fine-silty, mixed, superactive, thermic Pachic Argiustoll) with a pH of 6.6 (USDA-NRCS 1999). Mean (1980–2005) maximum and minimum temperatures during June through October were 37 and 20°C, respectively. The 25-year (1980–2005) average rainfall during the growing season (June–October) in 2003, 2004, and 2005 was 64, 130, 790, and 840 mm annually. Aver-

**Environmental Conditions**

Amount and distribution of precipitation during the study varied among years (Table I). Growing season precipitation (June to October) in 2003, 2004, and 2005 was 64, 130,
and 125%, respectively, of the long-term (25-year) average. Rainfall during 2003 was 61 and 54%, respectively, of the amounts received in 2004 and 2005. Maximum amounts of precipitation were recorded for June and October 2004 and June and August 2005, which provided 61 and 51%, respectively, of the growing season precipitation. Precipitation received in 2003 lacked the larger volumes recorded in the other years. Compared to long-term averages, segments of all three years could be described as drought affected.

Soil Water

Significant ($P < 0.01$) interactions were recorded in amounts of soil water between cultivar–fallow treatments, sampling date, and years for all four depths, indicating that a complicated relationship existed in the use and recharge of soil moisture within the profile (Fig. 1). To simplify our results, soil water responses for all forage cultivars were combined, since they were similar each year. The only exception was Tyrone—a leafier, later-maturing (maturity group VII) cultivar—during the last three sampling dates of 2003. Slightly less (~5%) soil water was recorded beneath Tyrone during that time period than under the other forage cultivars. The three-way interaction at all depths was primarily caused by variability in soil water among the three years of the study, with general declines recorded in 2004 and 2005 under the soybean treatments, compared to summer fallow. Large swings in soil water were also recorded in response to rain events during 2003 and 2005, particularly in the two uppermost layers. Most rains received during the study, with two exceptions (15 July 2004, 16 Oct. 2004), lacked the volume to
penetrate to the deeper sections of the soil profile. The average (±1 SE) soil water content under both types of soybean (across all depths and dates) was 21.0 ± 1.5% lower than the fallow treatment in 2004 and 2005, but only 6.7% lower during 2003. Overall, soil water content under the forage and grain soybean treatments were 16.2 ± 0.9% and 17.5 ± 1.5% lower than under summer fallow. Soil water under the fallow treatment was relatively stable across years and sampling dates in the three lower layers (20–35 cm, 35–50 cm, and 50–65 cm depths), and increased from 39.7 ± 2.9 mm to 56.5 ± 1.0 mm water per 15-cm soil depth over the growing seasons.

**Total Standing Crop**
Cultivar effects on standing crop were not significant ($F_{3,91} = 1.8; P = 0.22$) while year effects were significant ($F_{2,76} = 30.1; P < 0.01$). No interaction was recorded among cultivars and years ($F_{3,74} = 1.0; P = 0.47$). Standing crop in 2003 across cultivars was 45% of amounts produced in 2004 and 2005 (Table 2).

**Water Use and Water Use Efficiency**
Cultivar effects on water use were not significant ($F_{3,4.3} = 4.0; P = 0.10$) while year effects were significant ($F_{2,79} = 9880.2; P < 0.01$). Interactions between cultivars and years were not significant ($F_{6,77} = 3.6; P = 0.06$). The lowest water use occurred during 2003 (the driest year) with cultivars utilizing 229 ± 6 mm. Greater amounts of soil water were utilized by the cultivars in 2005 (582 mm) and 2004 (455 mm). Year effects on WUE were significant ($F_{2,7} = 7.2; P = 0.02$), while cultivar ($F_{3,71} = 2.9; P = 0.11$) and cultivar × year interactions ($F_{6,75} = 1.9; P = 0.20$) were not. Higher WUE were recorded for all cultivars during 2004 (16.0 kg ha$^{-1}$) than in 2003 or 2005 (Table 2). This was a 21 and 47% higher efficiency in water use, respectively, than was noted in 2003 and 2005.

**DISCUSSION**
There was no identifiable effect related to type or cultivar of soybean planted on amount of water used, WUE, or total standing crop. In contrast to our results, Specht et al. (1986) observed differences among soybean cultivars in response to a seasonal water gradient. All three forage cultivars used in this study were developed from the four-way (‘Wilson 6’ × ‘Forest’) × (‘Perry’ × L76-0253) cross (Devine and Hatley, 1998; Devine et al., 1998). As such, they had similar genetic potentials for responding to soil water. The greatest effect noted

<table>
<thead>
<tr>
<th>Year</th>
<th>Standing crop WUE</th>
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<tr>
<td></td>
<td>kg ha$^{-1}$ kg ha$^{-1}$ mm$^{-1}$</td>
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<tr>
<td>2003</td>
<td>3034ab$^1$ 13.2ab</td>
</tr>
<tr>
<td>2004</td>
<td>7271a 16.0a</td>
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<tr>
<td>2005</td>
<td>8410a 10.9b</td>
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$^a$Values with the same letter were not statistically different at $P < 0.05$. in our study was related to year, specifically the amount and timing of precipitation during the growing season, and the reduction in levels of soil moisture during 2004 and 2005. Total standing crop in 2003 (3034 kg ha$^{-1}$) was 45% of the amounts produced in 2004 and 2005. Though amount of soil water within the profile was highest during the 2003 growing season, the reduced level of production can be attributed to the limited precipitation received during the first growing season. Rainfall was 36% below the long-term average and an average of 57% less than in 2004 and 2005.

There is currently little information available on water requirements of forage or grain soybean in the SGP. In other regions, annual water consumption by soybean varied from 250 mm under dry conditions, to 840 mm under conditions of optimal water availability (FAO, 2000). Water requirements for maximum production were reported to vary between 450 to 700 mm and 450 to 800 mm per season depending on climate and length of growing period (FAO, 2002; EMBRAPA-Soja, 2002). Seasonal water availability in 2003 was 262 mm, which was 42% below the lowest reported water requirements for soybean. In comparison, the 534 and 515 mm received during the 2004 and 2005 growing seasons were within the requirements for maximum production.

Differences in water content of the soil profile for the summer cropped and fallow treatments became detectable 4 to 6 wk after seeding soybean. The most noticeable level of water use by both forage and grain-type soybean occurred in August through September, as plants were either flowering or forming pods. Similar results were reported in other studies (FAO, 2002; EMBRAPA-Soja, 2002). There was a higher level of WUE reported in the wettest year (2004), though there was no clear trend related to level of precipitation. The first year (2003) was the driest, but WUE was not different from values in 2004 or 2005, when both high (2004) and low (2005) WUE and high precipitation were recorded.

The effect of double-cropped soybean on soil water in this study appeared different from a study in central Oklahoma on how double-cropping soybean after winter wheat can affect soil water. Daniel et al. (2006) found soybean grown during the summer fallow period under conservation tillage practices reduced volume of runoff by 50% and lengthened time to initial runoff by 45% following simulated summer rainstorms (100 mm h$^{-1}$), compared to summer fallow. The root systems of soybean apparently provided pores in the soil profile that allowed rapid initial infiltration of water, thereby increasing amounts of soil water. However, though infiltration may be improved, it might not result in a net increase in soil water. Soybean will utilize available moisture in the profile to produce biomass and grain, so net improvements in soil water may not occur by the end of the growing season.

Results also showed the cumulative effect of double-cropping soybean (compared to summer fallow) after winter wheat on soil water over a three-year period, specifically reductions in available soil water during the succeeding
summer growing seasons. Despite some recharge in the fall, precipitation during both the fall and spring lacked the volume required to completely recharge the soil profile in all years. Wheat producers in the SGP rely on wheat as forage for grazing stocker cattle in the fall and winter, to augment returns per acre and improve profitability of wheat (Peel, 2003). Double-cropping soybean in the fallow period of winter wheat under dry conditions could have negative economic effects for producers (Redmon et al., 1995), unless soybean fixes enough N to offset potential losses from fall grazing. Rao et al. (2005) reported that forage soybean grown in the study area contained 28 g N kg⁻¹ forage during mid-August of 2001 through 2003. Though not precise, application of this value to levels of standing crop in this study indicates roughly 85, 203, and 235 kg N ha⁻¹ would be present in soybean forage during 2003 through 2005. Amounts in 2004 and 2005 would easily exceed the N requirements (110–123 kg N ha⁻¹) for a dual-purpose wheat crop (Redmon et al., 1995). Research is required to describe the trade-offs that may exist between production of wheat forage for fall grazing and fixation of N by double-cropping warm-season legumes in the SGP.

CONCLUSIONS

Prolonged dry periods occur regularly in the SGP (Garbrecht et al., 2000), and current models used to predict precipitation at the growing season scale are unreliable (Schneider and Garbrecht, 2003). Given the importance of soil water to wheat production in the SGP and the frequency of occurrence of dry periods, double-cropping soybean with winter wheat should be considered a short-term tactical tool for producing summer forage and be restricted to wetter years, when optimum production might be obtained. Alternatively, a multicrop rotation including wheat (fall through spring), soybeans (summer), winter fallow, and short-season spring forage or cover 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).

References

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