ABSTRACT

Crop production in the Southern Great Plains (SGP) is heavily dependent on irrigation from the Ogallala Aquifer, an underground water source that is rapidly declining (Guru and Horne, 2000; Maupin and Barber, 2005). Other parts of the region rely on surface water, which has also become limited due to long-term drought. The competition for water from other entities, such as the dairy industry (Hadjigeorgalis and Vendrely, 2007) and other social sectors, also exerts its share of pressure on declining water resources. Moreover, an increase in the costs associated with pumping from a declining groundwater source has become a great concern to the agricultural sector in the region.

Winter wheat, corn, and sorghum are the main crops of the SGP. Except for strictly dryland sorghum–wheat–fallow rotations, most cropping systems utilize irrigation. Corn production without irrigation is almost unthinkable in the region because precipitation is typically insufficient and unpredictable. However, drought-tolerant corn hybrids have been developed, and producers in the region are growing them with varied success (Marsalis, personal communication).

With declining water resources, maintaining the profitability of traditional crop production systems will be a challenge. Hence, making the present crop production systems more diversified, efficient, economical, and sustainable is very important. One possible option is to utilize adaptable, early maturing (around 100 days) crops/crop varieties that could be grown in the rainy months (June through September) with limited irrigation (250 to 304 mm).
Moreover, this approach may not only help growers to allocate part of their irrigated land to ultra-short to early season (early maturing) crops and less water demanding crops but also use the land and rainfall more efficiently.

Yields of ultra-short to early season crops can be comparable to full-season crops given the extra inputs necessary to achieve high yield with full-season crops (Keisling et al., 1999; Purcell and Vories, 2003). Corn and sorghum yields under full irrigation reported by Marsalis et al. (2010) in this region are comparable to the yields reported by Keisling et al. (1999) and Purcell and Vories (2003). Since yields of early maturing hybrids are comparable to full-season hybrids (which need extra irrigation), ultra-short to early season production systems could have potential to improve crop production systems in the SGP. Rao et al. (2003) reported yields ranging from 1200 to 5400 kg ha$^{-1}$ with an early maturing pigeon pea in the SGP. Canola varieties of different maturity groups, including early maturing types, with yields ranging from 358 to 4017 kg ha$^{-1}$ have been reported from a variety of test plots in North Dakota (Kandel, 2008). A yield potential greater than 1500 kg ha$^{-1}$ with advanced lines of canola has also been reported in Australia (Norton et al., 2004).

Ultra-short to early season crops that have shown acceptable yield potential with limited irrigation (about 50% of the water required to grow full-season crops such as wheat and corn) in other regions of the United States may have potential to become alternative crops in the SGP; however, they have not been explored under semi-arid local growing conditions. Consequently, opportunity exists for testing adaptability of advanced early maturing lines of crop species such as soybean developed for the Northern Great Plains (Helms et al., 2006), sunflower, pigeon pea, and canola in this region. Therefore, the objective of this study was to evaluate yield potential of diverse ultra-short to early season crop species, including warm-season cereal grains (corn and sorghum), oilseeds (canola, soybean, and sunflower), and grain legumes (pigeon pea and soybean), with limited irrigation in the SGP.

### MATERIALS AND METHODS

A field study involving ultra-short to early season cultivars of diverse crops was conducted at the New Mexico State University Agricultural Science Center at Clovis [34.60° N, 103.22° W, elev. 1331 m; Olton clay loam (fine, mixed, superactive, thermic Ardic Paleustolls)] in 2006 and 2007. Pre-plant incorporated fertilizer (112-45-0 kg N-P$_2$O$_5$-K$_2$O ha$^{-1}$ and 0.95 liter Zn ha$^{-1}$ in 2006 and 140-45-0-17 kg N-P$_2$O$_5$-K$_2$O-S ha$^{-1}$ and 2.9 liter Zn ha$^{-1}$ in 2007) was applied based on soil test recommendations for sorghum. Soybean (Jim, Trail, and Pembina), pigeon pea (GA-1 and GA-2), canola (Arid, Dahinda, and 45H21), sunflower (820HO and Hy-sun-511), sorghum cultivars (Pioneer 86G08 and Triumph-420), and a corn hybrid (Pioneer 39D82) were planted on 31 May 2006 and 1 June 2007.

In both years, crops were planted at a 76-cm row spacing into a conventionally tilled seedbed under sprinkler irrigation in 4-row (9 m x 3 m)
plots arranged in a randomized complete block design with four replications. Soybean, pigeon pea, canola, sunflower, sorghum, and corn were planted at the recommended seeding rates of 45, 10, 4.5, 5, 3, and 26 kg ha\(^{-1}\), respectively. In both years, un-inoculated seeds of legumes were used. After planting, weeds and insects were controlled each year as needed using labeled chemicals and methods, including hand hoeing.

Growing season weather data were collected from a National Weather Service station located at the Agricultural Science Center in Clovis. Sprinkler irrigations were applied as needed throughout the growing season, and approximately 15 to 30 mm of irrigation was applied every 2 to 4 days in 2006, while 19 to 40 mm of irrigation was applied every 3 to 5 days in 2007. In June 2007, crops were irrigated only twice because of adequate precipitation. Irrigation was terminated on 8 August 2006 and 13 September 2007. Irrigation was terminated earlier in 2006 than in 2007 because of adequate precipitation later in the growing season in 2006. Total applied water (monthly irrigation plus precipitation) amounts along with temperature and the long-term monthly temperature and precipitation are presented in Table 1.

Plots of each cultivar were harvested at maturity, leading to differences in harvest date and growing season length (Table 2). At harvest, all plants within 2 m of the two central rows were collected to the soil surface, bagged, and dried for 72 h at 65°C, after which plant materials were threshed and seed yields were estimated. Harvesting varieties by maturity led to a difference in the amount of precipitation in 2006 and both precipitation and irrigation received in 2007 (Table 2). Applied water use efficiency was calculated as kg ha\(^{-1}\) mm\(^{-1}\) [(seed yield, kg ha\(^{-1}\)) / (precipitation + irrigation, mm)]. Harvest index, or the ratio of grain to total biomass (grain plus aboveground dry matter), was calculated for each plot.

Statistical analyses were performed using SAS PROC MIXED procedures in SAS 9.2 (SAS Institute Inc., Cary, NC) to detect if differences existed between species and cultivars within species and their interactions with year. Significance was considered at \(P < 0.05\), and protected LSD was obtained using the PDIF1 statement in the LSMEANS option within SAS PROC MIXED to decide where differences occurred within significant interactions (Littell et al., 2002).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Cultivar</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>Jim</td>
<td>248.8</td>
<td>251.0</td>
</tr>
<tr>
<td>Soybean</td>
<td>Trail</td>
<td>248.8</td>
<td>251.0</td>
</tr>
<tr>
<td>Soybean</td>
<td>Pembina</td>
<td>248.8</td>
<td>251.0</td>
</tr>
<tr>
<td>Pigeon pea</td>
<td>GA-1</td>
<td>248.8</td>
<td>309.5</td>
</tr>
<tr>
<td>Pigeon pea</td>
<td>GA-2</td>
<td>248.8</td>
<td>313.5</td>
</tr>
<tr>
<td>Juncea canola</td>
<td>Arid</td>
<td>248.8</td>
<td>267.8</td>
</tr>
<tr>
<td>Juncea canola</td>
<td>Dahinda</td>
<td>248.8</td>
<td>267.8</td>
</tr>
<tr>
<td>Canola</td>
<td>45H21</td>
<td>248.8</td>
<td>286.5</td>
</tr>
<tr>
<td>Sunflower</td>
<td>820HO</td>
<td>248.8</td>
<td>267.8</td>
</tr>
<tr>
<td>Sunflower</td>
<td>Hysun-511</td>
<td>248.8</td>
<td>267.8</td>
</tr>
<tr>
<td>Sorghum</td>
<td>86G08</td>
<td>248.8</td>
<td>309.5</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Triumph-420</td>
<td>248.8</td>
<td>309.5</td>
</tr>
<tr>
<td>Corn</td>
<td>39D82</td>
<td>248.8</td>
<td>309.5</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Growing Conditions

Growing conditions in 2007 in general, and precipitation in particular, were comparable to the long-term total, but May and June—the critical time for crop establishment—were cooler in 2007 than both 2006 and the long-term averages (Table 1). Although there was more precipitation during June 2007 than June 2006, the total amount of water each crop species received through supplementary irrigation was greater for June 2006 than for June 2007 growing seasons (Table 1). July 2006 and July and August 2007 were dryer than normal; however, crop species in both 2006 and 2007 growing seasons received supplementary irrigation to offset this discrepancy (Tables 1 and 2).

Seed Yield and Harvest Index

Species and cultivars within species effects were significant for seed yield. For differences among species, seed yield of corn was significantly greater than all of the other crop species (Table 3). It was expected that the seed yield of corn would be greater than not only the legume and oilseed species but also the early maturing sorghum. Similar results were obtained at New Mexico State University’s Agricultural Science Center at Tucumcari, which is about 70 miles north by northwest of this study’s location (Angadi et al., unpublished data). Similar results have also been reported by Keisling et al. (1999) and Purcell and Vories (2003) just east of the SGP. Furthermore, seed yields of corn and sorghum recorded in this study were within the yield ranges previously reported under Mid-south and Southern Great Plains growing conditions (Hattendorf et al., 1988; Schneckloth et al., 1991; Howell et al., 1998). However, much greater seed yields were reported by some of the other researchers cited previously. Perhaps this is associated with the difference in growing conditions or irrigation and precipitation amounts, or even the variety used in our study compared to the other studies. Nevertheless, seed yields of corn in this study were within the ranges reported by Marsalis et al. (2010) from variety tests conducted in New Mexico. However, seed yields of sorghum in this study were lower than the yield reported by Marsalis et al. (2010), and this is perhaps due in part to differences in maturity and growing conditions.

Generally, seed yields of legume species recorded in our study (Table 3) were within the ranges reported in the Mid-south and Southern Great Plains (May et al., 1989; Kane and Grabau, 1992; Ishibashi et al., 2003) and were dependent on maturity group, planting date, and growing conditions, especially precipitation. Rao et al. (2003) in the SGP reported a seed yield of 1200 to 5400 kg ha\(^{-1}\) with early maturing (118 days) pigeon pea cultivars (GA-2 and ICPL 85010); cultivar GA-2 was also tested in our study.

As with corn, sorghum, and legumes, seed yields of oilseed species were generally within the ranges reported throughout the Great Plains. Yields ranging from 358 to 4017 kg ha\(^{-1}\) for canola and up to 2802 kg ha\(^{-1}\) for sunflower of early maturing types have been reported from variety test plots in North Dakota (Kandel, 2008), and the cultivars tested in our study have similar times to maturity as the variety tested in North Dakota. Moreover, one of the canola cultivars (45H21) tested in our study was also in the North Dakota variety trial, and its seed yield was within the range indicated previously. In Australia, Norton et al. (2004) reported yields great-

<table>
<thead>
<tr>
<th>Species</th>
<th>Seed yield (kg ha(^{-1}))</th>
<th>Total aboveground biomass (kg ha(^{-1}))</th>
<th>Harvest index</th>
<th>Applied water use efficiency (kg ha(^{-1}) mm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>7973(\text{a})</td>
<td>16610(\text{a})</td>
<td>0.48(\text{b})</td>
<td>15.9(\text{a})</td>
</tr>
<tr>
<td>Sorghum</td>
<td>4482(\text{b})</td>
<td>10671(\text{b})</td>
<td>0.42(\text{c})</td>
<td>8.8(\text{b})</td>
</tr>
<tr>
<td>Sunflower</td>
<td>2346(\text{c})</td>
<td>6174(\text{c})</td>
<td>0.38(\text{d})</td>
<td>4.8(\text{c})</td>
</tr>
<tr>
<td>Soybean</td>
<td>1479(\text{c})</td>
<td>2689(\text{d})</td>
<td>0.55(\text{a})</td>
<td>3.1(\text{c})</td>
</tr>
<tr>
<td>Pigeon pea</td>
<td>1624(\text{c})</td>
<td>4274(\text{c})</td>
<td>0.38(\text{d})</td>
<td>3.2(\text{c})</td>
</tr>
<tr>
<td>Canola</td>
<td>1349(\text{c})</td>
<td>4652(\text{c})</td>
<td>0.29(\text{c})</td>
<td>2.8(\text{c})</td>
</tr>
</tbody>
</table>

\(\text{†}\) Means followed by the same letter within the same column are not significantly different at \(P < 0.05\).
er than 1500 kg ha\(^{-1}\) with advanced lines of canola. Thus, most of the crop species tested in our study have shown the potential to be adapted to and produce acceptable seed yields with limited applied irrigation water (291.3 mm total, averaged over years).

The significant cultivar within species effect was detected only for sorghum (5374 vs 3590 kg ha\(^{-1}\) for 86G08 and Triumph-420, respectively, \(P < 0.0001\)), suggesting that cultivars of other crop species we included in our study have similar seed yield potential. Triumph-420 is a very early maturing cultivar, and the lower yield potential under similar growing conditions therefore seemed reasonable. It is also anticipated that mean sorghum yields would have been higher, considering the total amount of water (irrigation plus precipitation) in the system, if longer-maturing hybrids had been used. Grain sorghum varieties have been shown to yield more than this with less total water at the same locations (Marsalis et al., 2010).

The species effect was significant for harvest index. Harvest index was significantly higher for soybean than other crop species. The second-highest harvest index value was recorded for corn and the lowest index for the small-seeded oilseed crop species canola (Table 3). The cultivar within species effect was significant for harvest index, but the significant difference between cultivars was detected only within sorghum (0.43 vs 0.37 for 86G08 and Triumph-420, respectively; \(P = 0.0444\)) and pigeon pea (0.36 vs 0.23 for GA-2 and GA-1, respectively; \(P = 0.0030\)); however, as previously described, unlike sorghum, seed yields of pigeon pea cultivars were not significantly different from each other.

After corn and sorghum are harvested for grain, the residues can be grazed by livestock, providing additional benefit to farmers. The crop residues of broadleaf species were less than cereals (2748 vs 7413 kg ha\(^{-1}\), averaged over species, with soybean producing the lowest with 1210 kg ha\(^{-1}\), and corn producing the highest with 8637 kg ha\(^{-1}\)). Nevertheless, farmers may still benefit by growing these crops for oil production and using the leftovers from oil extraction as a protein-rich feed source for animals, including confined livestock operations. In addition, including broadleaf species as part of the cropping system would bring rotational benefits, such as improving soil fertility, breaking pest lifecycles, and reducing farm inputs (Bailey et al., 2001; Lafond et al., 2006; Boyles et al., 2007).

These are some of the elements to make crop production systems more resource use efficient, economical, and sustainable.

**Applied Water Use Efficiency (AWUE)**

Even though corn, sorghum, and pigeon pea received less total irrigation and precipitation in 2007 than in 2006, their AWUE was numerically greater in 2007 than the 2006 growing season (data calculable from Table 2). However, a significant difference between years was detected only for corn, leading to a year x species interaction for AWUE (14.0 vs 17.7 kg ha\(^{-1}\) mm\(^{-1}\) for corn in 2006 and 2007, respectively, \(P = 0.0495\)). The other crops (soybean, sunflower, and canola) had numerically higher AWUE in 2006 than in 2007, which may have contributed to an interaction of rank. The higher AWUE also relates well to the higher amount of irrigation and precipitation these crops received in 2006 compared to 2007 (Table 2). The reason for the opposite trend seen with corn, sorghum, and pigeon pea was unclear, except that the warmer temperature in June and July of 2006 (Table 1) combined with the well-distributed application of irrigation (approximately 15 mm every 3 days) given to the crops in the first 3 weeks of June of 2006 may have helped these crops to establish well with good early and subsequent vegetative growth. On the other hand, in the first 3 weeks of June of 2007, crops were left to rely more on the higher precipitation received, but this was not well distributed and perhaps had a negative impact on the overall crop establishment and vegetative growth. Despite the significant interaction, the main effect of species was also significant (\(P < 0.0001\); Table 3).

Generally, AWUE was the highest for corn followed by sorghum, which was higher than all other crops. However, no significant differences were detected among sunflower, soybean, canola, and pigeon pea for AWUE, and this may demonstrate their similarity in terms of water use and perhaps their adaptability to the limited irrigation regime to which they were subjected (about 1 inch per week, which is less than half of the amount required to grow full-season crops such as wheat and corn). Applied water use efficiency of the broadleaf species was lower compared to cereal grass species commonly grown in the SGP (sorghum and corn). This was expected since C\(_4\) species, such as sorghum
and corn, are generally known to be more water use efficient than \( \text{C}_3 \) plants. In addition, protein in legumes and oil content in oilseed crops is much higher than corn and sorghum. The physiological cost of producing protein and lipids is much higher than that of producing carbohydrates (Sinclair and DeWit, 1975; Thornley and Hesketh, 1972). The AWUE results of the corn tested in this study were within the range reported by Howell et al. (1998) in Texas, by Corak et al. (1991) in Kentucky, and by Norwood (1999) in Kansas for corn and sorghum. Our measured applied water use efficiency of legumes and oilseed crops is similar to the results of water use efficiency of legumes and oilseed crops reported by Norwood (1999) in Kansas, by Varvel (1995) in Nebraska, and by Azooz and Arshad (1998) in British Columbia.

**CONCLUSION**

The ultra-short to early season crops studied showed promise in the Southern Great Plains. Even if yields are lower than full-season types grown with a longer duration of irrigations, profitability may be maintained—or perhaps enhanced—if yield per unit of water applied is similar between the two scenarios. Pumping costs are one of the primary input incumbencies of irrigated systems. Moreover, including legumes (such as pigeon pea and soybean) and oilseeds (such as canola, soybean, and sunflower) in cropping systems of the region would not only bring the well-known benefits of rotation to crop production systems but may also have the potential to produce an energy source and a protein-rich feed for the large dairy and beef industries in the region. However, more research is needed for an in-depth assessment, especially with regard to soil fertility and irrigation requirements of the individual crops.

**ACKNOWLEDGMENTS**

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**LITERATURE CITED**


Sultan Begna is an agricultural research scientist at NMSU’s Agricultural Science Center at Clovis. He earned his M.S. in agronomy and Ph.D. in agronomy and crop physiology from McGill University in Montreal, Canada. His current research program involves diverse crops aimed at improving resource use (particularly water and soil) and diversifying the cropping systems in eastern New Mexico.