GROWING DRYLAND CROPS IN CLUMPS: WHAT ARE THE BENEFITS?

B.A. Stewart[1*]

[1]West Texas A&M University, Canyon, TX
[*]Corresponding author's e-mail address: bstewart@mail.wtamu.edu

ABSTRACT

Stored soil water and growing season precipitation generally support early-season growth of summer crops such as grain sorghum (*Sorghum bicolor* L. Moench) in dryland areas but are insufficient to prevent water stress during critical latter growth stages. The objective of this study was to determine if growing plants in clumps affected early season growth and subsequent grain yield compared to uniformly spaced plants. We hypothesized that growing corn and grain sorghum plants in clumps would result in fewer tillers and less vegetative growth so that more soil water would be available during the grain filling period. A corn (*Zea mays*) study was conducted at Canyon, TX and grain sorghum studies were conducted at Bushland, TX and Tribune, KS. Results showed that planting plants in clumps reduced tiller formation and vegetative growth. Grain sorghum yields were increased by clump planting by as much as 100% when yields were in the 1000 kg ha^{-1} range and 25 to 50% in the 2000 to 3000 kg ha^{-1} range, but there was no increase or even a small decrease at yields above 5000 kg ha^{-1}. The results suggest that plants in clumps rather than spaced uniformly conserves soil water use until later in the season and may enhance grain yields in semiarid dryland environments.

INTRODUCTION

The southern High Plains is a hostile environment for growing crops without irrigation. Although the region is classified as semiarid, much of it is very close to being arid. The aridity index (Stewart, 1988) is commonly used to classify climates and is determined by dividing the average annual precipitation by the average annual potential evapotranspiration (PET). A location with an index > 0.20 and < 0.50 is considered semiarid. Amarillo, TX has an index of about 0.25. Perhaps even more important, there is not a single month in Amarillo when the average precipitation is as much as 50 percent of the average monthly PET. Therefore, successful dryland cropping in the region depends on plant available water stored in the soil profile at time of planting to supplement the growing season precipitation.

Grain sorghum is a major crop grown under semiarid conditions in the United States and other parts of the world. It is one of the most widely grown dryland crops in the southern Great Plains, but grain yields are generally low and highly variable because of sparse and erratic growing season precipitation. Average yields from 1972 to 2004 were 2530 (CV 28) for southwest Kansas, 2280 (CV 23) for the North Texas High Plains, and 1860 kg ha^{-1} (CV 28) for the South Texas High Plains (National Agricultural Statistics Data Base, 2006). Yields would be considerably lower if based on planted areas because only 90 (CV 8), 79 (CV 18) and 81% (CV 22) of the average planted areas actually were harvested for grain (National Agricultural Statistics Data Base, 2006). The yields and percent of area harvested tend to decrease moving from north to south as drier conditions occur. A lack of water during the reproduction and grain filling stages is common and the major cause of low grain sorghum yields in the U.S. southern

Great Plains. Craufurd et al. (1993) reported that water stress during booting and flowering stages resulted in grain yield reductions of up to 85%. Strategies such as reduced plant populations, different spacing between rows, and skip row configurations have been used with varying degrees of success to enhance soil water contents later into the growing season (Blum and Naveh, 1976; Larson and Vanderlip, 1994).

EFFECTS OF TILLERS

A tiller is a shoot that sprouts from the base of a grass plant. Tillers are very common on grain sorghum (*Sorghum bicolor* L. Moench) plants, and to a lesser extent on corn *(Zea mays)* plants. Although the factors for tiller formation are many and complex, tillers generally signal favorable growing conditions. Tillers are morphologically the same as the main stalk and can form their own roots, nodes, leaves, and panicles or ears. Tillers can even form additional tillers when conditions are favorable. However, since tillers develop later than the main stalk, they often lose out in the competition for water, nutrients, and light and quit growing or even die.

Tillers can compensate for skips in a row and for main stalks damaged by hail, frost, wind, etc. Therefore, tillers are considered by many scientists and producers to be a positive trait. Others, however, believe that tillers can lead to a reduction of grain yields and it was once common for farmers in the Cornbelt to remove tillers from corn plants (Nielsen, 2003). The consensus thinking of agronomists in the Cornbelt today, however, is that tillers on corn plants do not have a negative effect of the ears of the main stalks (Thomison, 2003). Water is often not limiting in the Cornbelt whereas it is essentially always the limiting factor for crops grown without irrigation in the southern Great Plains.

My interest regarding the effects of tillering on plant growth and development began by years of observing grain sorghum plants under dryland conditions. The primary management practice that scientists and farmers tried to conserve stored soil water for use during the latter growth stages was to reduce plant density. Many extension specialists and scientists recommended grain sorghum plant populations as low as 3 plants m^{-2}. Even with these low plant populations, severe water stress occurred in most years. Numerous observations and studies showed that as plant densities decreased, the number of tillers per plant increased. In some cases, the tillers produced panicles and contributed to grain yield, but in many cases the tillers did not produce panicles or if they did, the number and size of grains were small. Therefore, much of the expected benefit of a lower plant density was negated by an increased number of tillers that also depleted soil water for vegetative growth.

The reason that growing dryland grain sorghum plants in the southern Great Plains, particularly when the plants are widely spaced, form several tillers is easily understood by analyzing the PET and growing season precipitation data. Using Bushland, TX as an example (Table 1), there is enough precipitation to meet a substantial portion of the PET during the vegetative growth stages. Also, there is generally a significant amount of plant available water stored in the soil at the time of seeding. Jones and Johnson (1996) showed in a 9-yr study at Bushland that dryland grain sorghum used 84 mm of stored soil water. This accounted for 22% of the ET, and much of it was used for vegetative growth. Therefore, early season precipitation and stored soil water are generally adequate for dryland grain sorghum during the early growth stages and along with warm temperatures, good soil fertility, and abundant sunshine, growing conditions are favorable and conducive for tiller formation. However, average precipitation during the reproduction and grain filling stages is less than 30 percent of the PET (Table 1), and with much of the stored soil water already utilized, water stress during these critical stages is common and often severe.

My interest in plant geometry was further stimulated by Brown (1985) discussing the way the Hopi and Papago Indian Tribes grow corn in deserts of Arizona and New Mexico. The corn is planted in hills about 2 m apart with 10 to 12 plants per hill. They learned that the clumping of plants within a relatively small space reduces the desiccation of the foliage, the anthers and silk thereby allowing normal fertilization to occur in that extremely arid environment. Weatherwax

Table 1. Long-term average precipitation during various growth stages of grain sorghum seeded on June 1 at Bushland, TX.

Crop Stage	Days	PET, mm	Precipitation, mm	Pct./PET (%)[†]
Day 1 to 3-leaf	23 (9) [†]	64 (11)	50 (87)	78
3-leaf to flag leaf	30 (7)	151 (9)	64 (65)	42
Flag leaf to flowering	21 (10)	131 (11)	37 (69)	28
Flowering to black layer	37 (11)	191 (8)	57 (71)	30
Total	111 (6)	537 (7)	208 (44)	39

Source: 14 yr potential evapotranspiration (PET) data from Texas A&M University Research and Extension Center (2005)
[†]Percentage of potential evapotranspiration supplied by precipitation for the various growth stages.
[‡]Numbers in parentheses are CV values.

(1954) also describes growing corn in clumps in his book, *Indian Corn in Old America*. When Weatherwax asked a Native American why corn plants are grown this way, the Native American answered that "he has tried various way, and this one yields more corn" Weatherwax pressed him for more details and the Indian answered: "but sometimes he says that in the compact cluster the plants suffer less damage from the wind."

My students, colleagues, and I have carried out a number of studies with corn and grain sorghum to study the effect of tillers on plant development and grain yields. Our hypothesis has been that growing plants in clumps will increase plant competition so that growing conditions in the vegetative stages will be less favorable than when plants are spaced several cm apart as commonly done under semiarid conditions. The increased competition will result in less use of water, nutrients, and sunlight by the clump plants and there will be less vegetative growth, largely because of less tillering. This will leave more water for use by the plants during the reproduction and grain filling growth stages and result in higher grain yields. Limiting resources early in the season will limit yield potential, but under dryland conditions, early season yield potential is usually not a realistic goal. Brief summaries of these studies follow.

1990 Grain Sorghum Study at Bushland, TX

Brar and Stewart (1991) conducted a field experiment with two planting geometries (clump and row) and three densities (3, 6, and 9 plants m^{-1}). Rooting depth measurements indicated that rooting was significantly deeper with clumps than with traditional row planting before panicle formation and a reversed trend occurred after panicle formation. The deeper rooting during early growth stages was contributed to increased plant competition because of a higher plant density. Observations of biomass and grain yields indicated a superiority of clumps compared to rows but this was not borne out by statistics.

1999 Corn Study at Canyon, TX

Ashizawa (2000) grew corn in two different spacing patterns in rows 1 m apart. The plant spacings within the rows were single plants 33 apart and 3 plants in a clump with 1 m between clumps. After 52 days, there was an average of 2 tillers for each uniformly spaced corn plant compared to only 0.5 tillers for each plant in a clump. The clump plants yielded 4,550 kg ha^{-1}, 240 kg ha^{-1} more than the uniformly spaced plants, but the difference was not statistically significant. The uniformly spaced plants produced 10,990 kg ha^{-1} aboveground biomass that was significantly more than the 9,570 kg ha^{-1} produced by the clumps. The difference in the dry matter production occurred mostly early in the season and was largely attributed to tillers. The harvest index (dry weight of grain / dry weight of aboveground biomass) values were 0.41 for the clumps compared to 0.34 for the uniformly spaced plants and the difference was significant. The higher harvest index value for the clumps is an indication that the clump plants suffered less stress than the uniformly spaced plants. The clump plants also showed less visual water stress during the latter growth stages.

2002, 2003, and 2004 Grain Sorghum Studies

Field experiments were conducted at the USDA Conservation and Production Research Laboratory at Bushland, TX in 2002, 2003, and 2004, and at the Southwest Research and Extension Center at Tribune, KS in 2004. The hypothesis was that growing grain sorghum plants in clumps would limit tiller formation and change the plant architecture so that less soil water would be used during the vegetative growth period. The objective was to compare clumps of plants to the same number of individually spaced plants and determine the number of tillers produced, biomass and leaf area production during different growth stages, water use during vegetative and reproduction stages, grain yields, and harvest index values. Although the hypothesis and objective remained constant, the number of treatments and complexity of the experiments increased each year as results led to the need for additional approaches and information. The designs, methodologies, and results of these studies have been presented by Bandura et al. (2006) so only selected data and brief summaries of the findings are presented in this paper.

2002 Bushland, TX Study

Uniformly spaced grain sorghum plants developed 3 tillers per plant while plants in clumps had only 1 tiller. However, the clumped plants produce 2230 kg ha^{-1} grain compared to only

1290 kg ha^{-1} for the uniformly spaced plants. The yields were lower than anticipated for the region and were attributed to the lack of growing season precipitation and an insufficient supply os stored soil water during critical growth stages. The harvest index (grain / aboveground biomass) was 0.44 for the clump plants, almost double the 0.24 value for the uniformly spaced plants. The clump plants also reached the 50% bloom stage 5 d earlier and this could be an important factor for increasing water use efficiency.

2003 BUSHLAND, TX STUDY

Early season precipitation was above average resulting in favorable growing conditions during initial plant development. However, precipitation for the remainder of the growing season was less than 50% of the average and led to extreme water stress at anthesis and during grain filling growth stages (Bandaru, 2006). There were approximately 3 tillers for every plant when the plants were spaced approximately 17 cm apart within rows spaced 75 cm apart. In comparison, plants growing in clumps of 6 plants spaced 75 cm apart averaged less than 1 tiller per plant (Table 2). The clump plants produced significantly less biomass during the first 60 d and had a smaller leaf area index. Although the treatment with the uniformly spaced plants had many more tillers and therefore had the potential of producing many more panicles, the treatment with clumps actually produced more panicles and this resulted in a higher grain yield. These results indicate that much of the stored soil water was used to produce tillers during the early growth stages and that these tillers could not be sustained so they did not produce panicles and the increased water stress reduced panicle formation on many of the main stalks. Grain yields were low but the clump plants produced about two times as much grain as the uniformly spaced plants and a significantly higher harvest index (Table 2).

Table 2. Mean values of grain sorghum measurements in the 2003 Bushland, TX experiment[†].

	Pioneer 87G57		NC+5C35	
	Spaced plants	Clump plants	Spaced plants	Clump plants
Tillers per plant	0.6b[‡]	3.1a	0.6b	3.0a
Biomass 60 d (kg ha^{-1})	2687b	3697a	2717b	3440a
Leaf area index 60 d	1.03b	1.50a	1.04b	1.48a
Panicles m^{-2}	6.9a	4.3b	6.2a	4.3b
Grain yield (kg ha^{-1})	1135a	544b	1007a	607b
Harvest index	0.28a	0.13b	0.27a	0.13b

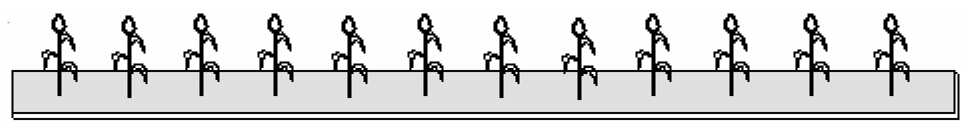
[†]Adapted from Bandaru et al., 2006.
[‡]Letters are that different in a row indicate significant differences by LSD mean separation at the *P* <0.05 level.

2004 BUSHLAND, TX STUDY

Five plant configurations were included in six field experiments. The experiments were located on the upper, middle, and bench positions of a bench-terraced watershed that included both stubble-mulched and no-tilled areas. The different positions contained different amounts of stored soil water at time of planting and there were also different amounts of runoff and run-on of precipitation during the growing season. The six experiments were conducted simultaneously and were adjacent to one another but they were analyzed statistically as individual experiments. Plants were spaced uniformly every 25 cm in a row (SP-25), every 25 cm in a row with all tillers removed (SP-25-TR), every 38 cm in a row (SP-38), clumped every 75 cm in a row with three plants in a clump (C3-75), and clumped every 100 cm in a row with four plants in a clump (C4-100, Fig. 1). All plots were hand-planted with Pioneer-8699 seed and thinned to the desired populations. Final plant densities for the Sp-25, C3-75, C4-100, and SP-25-TR treatments were equal at 5.4 plants m^{-2}, and 3.6 for the R-38 treatment.

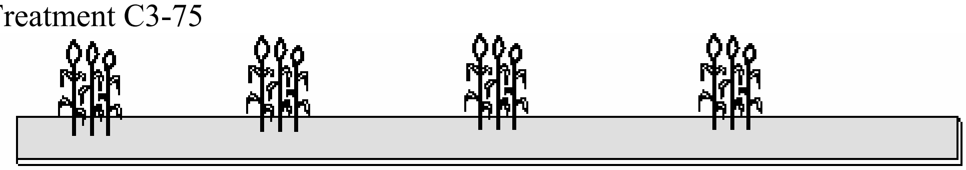
Weather conditions during 2004 were more favorable for grain production than for 2002 and 2003. The June through September precipitation was 306 mm, 42 mm above the long-term average.

Treatment SP-25



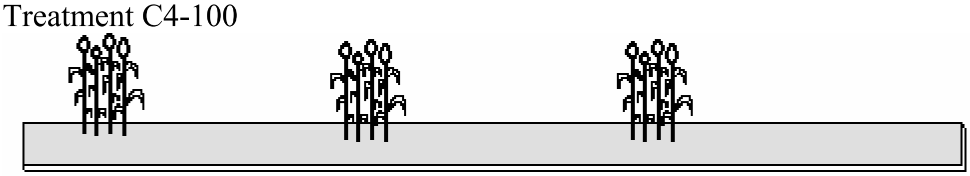
Single plants every 25 cm in 75 cm rows (5.4 plants m^{-2})

Treatment C3-75



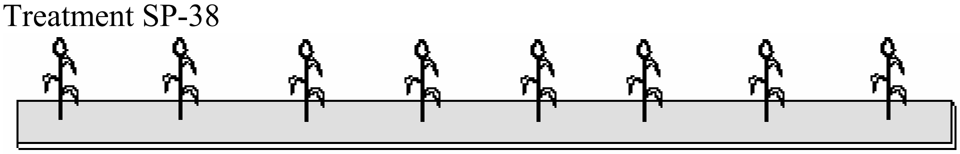
Three plants per clump every 75 cm in 75 cm rows (5.4 plants m^{-2})

Treatment C4-100



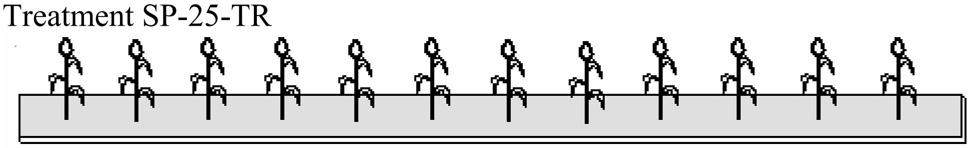
Four plants per clump every 100 cm in 75 cm rows (5.4 plants m^{-2})

Treatment SP-38



Single plants every 38 cm in 75 cm rows (3.6 plants m^{-2})

Treatment SP-25-TR



Single plants every 25 cm in 75 cm rows (5.4 plants m^{-2})
Tillers removed by hand when formed

Figure 1. Schematic showing plant geometries for the treatments used in the 2004 experiments at Bushland, TX and Tribune, KS.

Planting geometry had a significant effect on the number of tillers produced in all experiments. Results from the three experiments located on the stubble-mulched tillage area are shown in Table 3 were similar to those for the no-tilled area. The SP-25 treatment represents a commonly used geometry for dryland grain sorghum in the southern Great Plains. Plants produced approximately two tillers per plant. Although the experiments located on different positions cannot be compared statistically, there was a trend for plants on the middle and bench position to produce more tillers than those growing on the upper position where water conditions were less favorable. Tiller numbers were also influenced by distance between plants as shown by comparing the results for the SP-25 and SP-38 treatments (Table 3).

Aboveground biomass and leaf area produced during the initial 42 d of growth were closely related to tiller production (Table 3). Treatment SP-25 produced approximately 75% more dry matter and leaf area than the C4-100 treatment. The SP-25-TR treatment that had the tillers removed as they were formed produced essentially the same amounts of dry matter and leaf area as the C4-100 treatment, supporting the hypothesis that the increased dry matter and leaf area for the SP-25 treatment was the result of more tillers.

Although there were large differences in the number of tillers for the various treatments (Table 3), the differences in the number of panicles produced were much smaller. This was because a large percentage of the tillers, particularly for the experiment located on the upper position of the benched-terrace where water stress was more severe, did not produce panicles.

Grain yields were relatively high for experiments located on the bench position (Table 3) because this position received runoff from experiments located on other slope positions. There were no differences in yields between the clump treatments C3-75 and C4-100, and the spaced plant treatments SP-25 and SP-38 for experiments on the bench. However, the yield of the SP-25-TR treatment that had tillers removed was reduced. This reduction was likely caused by an insufficient number of panicles for the yield level achieved with the favorable water conditions.

The results were vastly different for the experiment on the upper slope position where water was very limited. For this experiment, the clump treatments produced more grain than the SP-25 treatment (Table 3). The C4-100 treatment produced more grain than the C3-75 treatment. The SP-38 treatment had one-third fewer plants ha^{-1} than the SP-25 treatment and there was a trend for increased grain yield but the increase was not statistically significant. The clumps also produced higher yields when compared to the uniformly spaced plants for the experiment conducted on the middle slope position, although the percentage increase was not as great as for the upper position experiment. The increased grain yields for the clump treatments were because of a higher harvest index (weight grain/weight aboveground biomass) and not because of increased biomass production.

2005 Tribune, KS Study

The winter and early spring precipitation was extremely low. However, amounts during June, July, and August were among the highest ever recorded (Bandaru, 2006). This led to very favorable growing conditions for dryland grain sorghum and resulted in grain yields similar to those for irrigated fields.

The number of tillers produced on the various treatments at Tribune in 2004 (Table 4) closely paralleled those found at Bushland in that year (Table 3). The clump treatments produced fewer tillers than the uniformly spaced plant treatments.

Table 3. Mean values for measurements of grain sorghum as affected by five planting geometries in 75-cm rows in 2005 Bushland, TX study on upper (Upper), middle (Middle) and bench (Bench) positions† of a stubble-mulched area.‡

Planting geometry§	Tillers plant^{-1} 28 DAP¶	LAI 42 DAP (kg ha^{-1})	Panicles m^{-2}	Grain (kg ha^{-1})	Harvest index
Upper					
SP-25	2.3a#	1.31a	8.1a	2385c	0.28c
C3-75	0.7b	1.01b	7.7a	2976b	0.36b
C4-100	0.3b	0.87c	6.2b	3563a	0.41a
SP-38	3.1a	1.30a	8.0a	2702bc	0.30c
SP-25-TR	Removed	0.85c	5.4c	2964b	0.39a
Middle					
SP-25	2.0a	1.41a	10.6a	3180c	0.34c
C3-75	1.1b	1.12c	9.5b	4013a	0.41ab
C4-100	0.5c	0.90d	8.1b	3952a	0.44a
SP-38	2.6a	1.37b	10.0a	3610ab	0.38b
SP-25-TR	Removed	0.88d	5.4c	3563bc	0.40b
Bench					
SP-25	2.3a	1.44a	12.0a	4743a	0.41b
C3-75	1.2b	1.18c	9.9bc	4902a	0.46a
C4-100	0.8c	0.93d	8.8c	4810a	0.46a
SP-38	2.9b	1.42b	10.8b	4911a	0.41b
SP-25-TR	Removed	0.91e	5.4c	4247b	0.42b

†Separate but identical experiments were conducted on three positions that had different amounts of stored soil water at time of seeding and different amounts of runoff or run-on during the cropping season.
‡Adapted from Bandaru et al., 2006.
§Planting geometries were SP-25 (plants every 25 cm), C3-75 (clumps of 3 plants every 75 cm), C4-100 (clumps of 4 plants every 100 cm), SP-38 (plants every 38 cm), and SP-25-TR (plants every 25 cm with tillers removed by hand) in 75 cm rows.
¶Days after planting (DAP)
#Means in columns for a position on the benched terrace followed by the same letter are not significantly different according to a protected LSD mean separation (*P* <0.5 level); each position represents a separate experiment and cannot be compared statistically.

Clumps did not show any yield advantage in this study, and this was not surprising considering the extremely high yield level (Table 4). The C4-100 treatment decreased yield, but the reduction was only 10 to 15%. The C4-100 treatment produced the lowest number of tillers and the relatively low plant population coupled with low tiller formation likely did not produce an adequate number of panicles for maximum yield. The SP-25-TR treatment reduced yields by 25 to 30%, likely due to the low number of panicles that were produced. Observations made during harvest suggested that yields were limited by lack of panicles because they were so large that stalk breakage was common. The fact that clumps depressed sorghum grain yields only about 10% under very favorable growing conditions is important because it indicates minimal downside risk with the use of clumps under dryland conditions even when seasonal precipitation is greater than normal.

Table 4. Mean values of measurements for grain sorghum as affected by five planting geometries in 75-cm rows in experiments at Tribune, KS in 2004[†].

Planting geometry[‡]	Tillers plant^{-1} 28 DAP[§]	Grain (kg ha^{-1})	Harvest index value
Stubble mulched area[¶]			
SP-25	2.3a[#]	6206b	0.43a
C3-75	1.0b	6090b	0.47a
C4-100	1.1b	5691c	0.48a
SP-38	3.1a	6472a	0.43a
SP-25-TR	Removed	4410d	0.43a
No-tilled area[¶]			
SP-25	2.3a	6408b	0.45a
C3-75	1.2b	6426b	0.48a
C4-100	1.0b	6054c	0.48a
SP-38	3.1a	6662a	0.44a
SP-25-TR	Removed	4707d	0.48a

[†] Adapted from Bandaru et al., 2006.
[‡]Planting geometries were SP-25 (plants every 25 cm), C3-75 (clumps of 3 plants every 75 cm), C4-100 (clumps of 4 plants every 100 cm), SP-38 (plants every 38 cm), and SP-25-TR (plants every 25 cm with tillers removed by hand) in 75 cm rows.
[§]DAP = days after planting.
[¶]Separate but identical experiments were conducted on stubble-mulched and no-tilled areas.
[#]Means in columns for a tillage area followed by the same letter are not significantly different according to a protected LSD mean separation (P < 0.5 level); each tillage area represents a separate experiment and cannot be compared statistically.

CONCLUSIONS

In the southern Great Plains, dryland grain sorghum is commonly seeded during the wettest period of the year when plant available water is abundant in the soil profile. Bandaru et al. (2006) showed that growing plants in clumps compared to uniformly spaced plants reduced the number of tillers and vegetative growth. This preserved soil water until reproductive and grain filling growth stages, which increased grain yield. There were marked differences in plant architecture of uniformly spaced plants compared to clumped plants. Uniformly spaced plants produced more tillers and the leaves on both the main stalk and tillers grew outward, exposing essentially all of the leaf area to sunlight and wind. In contrast, clumped plants grew upward with the leaves partially shading one another and reducing the effect of wind, thereby reducing water use. The benefit of clumps decreased as grain yields increased, and there was even a slight decrease when yields exceeded 6000 kg ha^{-1}. However, dryland grain sorghum yields seldom reach this level in semiarid regions so growing grain sorghum in clumps appears to be a useful strategy with little downside risk.

REFERENCES

Ashizawa, K. 2000. Responses of dryland corn (*Zea mays* L.) to two different plant spacings. Master of Science Thesis, West Texas A&M University.

Bandaru, V., B.A. Stewart, R.L. Baumhardt, S. Ambati, C.A. Robinson, and A. Schlegel. 2006. Growing dryland grain sorghum in clumps to reduce vegetative growth and increase yield. Agron. J. (in press).

Blum, A., and M. Naveh. 1976. Improved water use efficiency in dryland grain sorghum by promoted plant competition. Agron. J. 68:111-116.

Brar, G.S. and B.A. Stewart. 1991. Dryland sorghum response to planting geometry and density. Agron. Abstr. 139.

Brown, W.L. 1985. New technology related to water policy ─ plants. p. 37-41. In: W.R. Jordan (ed.) Water and Water Policy in World Food Supplies. Proceedings of Conference on Water and Water Policy in World Food Supplies, May 26-30, 1985, College Station, TX. Texas A&M University Press.

Craufurd, P.Q., D.J. Flower, and J.M. Peacock. 1993. Effect of heat and drought stress on sorghum (*Sorghum bilcolor*). I. Panicle development and leaf appearance. Exp. Agric. 29:61-76.

Larson, E.J., and R.L. Vanderlip. 1994. Grain sorghum yield response to nonuniform stand reductions. Agron. J. 86:475-477.

National Agricultural Statistics Data Base. 2006. Quick Stats: Agricultural Statistics Data Base. United States Department Agriculture, Washington, DC. [Online]. Available at http://www.nass.usda.gov/QuickStats/ (verified April 3, 2005).

Nielsen, R.L. 2003. Tillers or "Suckers" in Corn: Good or Bad? http://www.agry.purdue.edu/ext/corn/news/articles.03/Tillers-0623.html (verified April 5, 2006)

Stewart, B.A. 1988. Dryland Farming: The North American Experience. p. 54-59. In: P.W. Unger, T.V. Sneed, W.R. Jordan and R. Jensen (eds.) Challenges in Dryland Agriculture: A Global Perspective. Proceedings International Conference Dryland Farming, August 15-19, 1988, Amarillo/Bushland, TX. Texas Agricultural Experiment Station, College Station.

Texas A&M University Research and Extension Center. 2005. Texas High Plains Evapotranspiration Network. Available at http://txhighplainset.tamu.edu/terminology.jsp (verified April 3, 2006).

Thomison, P.R. 2003. Corn Growth and Development ─ Does Tillering Affect Hybrid Performance? AGF-121-85. Ohio State University Extension, Columbus. http://www.lgseeds.com/lg_tech/resources/Tillering%20of%20Corn.pdf (verified April 5, 2006).

Weatherwax, P. 1954. Indian Corn in Old America. Macmillan, New York.