TILLERING IN DRYLAND GRAIN SORGHUM CLUMPS AS INFLUENCED BY LIGHT, PLANTING DENSITY AND GEOMETRY

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ABSTRACT

Tillering is an important morphological component of grain sorghum (*Sorghum bicolor* L. Moench) development because it affects light capture, water use, grain yield, plant competition and other physical and biological processes. Our objective was to determine light and temperature differences associated with different tillering patterns when grain sorghum plants grown in clumps were compared with uniformly spaced plants. Four planting geometries and four plant densities were tested in two separate experiments at Bushland, TX in 2005. In experiment one, four plants seeded (adjacent to each other, 2.5 cm apart from each other in a square pattern, and 10 cm apart from each other in a square pattern) were compared to uniformly spaced plants (25 cm apart) in rows. In experiment two, four plant densities (clumps spaced 75 cm apart in 75 cm rows with one, two, four, and six plants per clump) were studied. Red/far-red (R:FR) light ratio, temperature, tiller number, crop phenology, and leaf number were measured in both experiments. Results of both experiments, showed no treatment effects on plant temperature, due to an absence of water stress associated with good soil moisture conditions after the five-leaf stage. Number of tillers plant^{-1} and R:FR ratio increased with increasing distance between plants in clumps. Additionally, the number of tillers plant^{-1} and R:FR ratio decreased with increasing plant density. Planting dryland grain sorghum in clumps of four plants with plants 2.5 cm or less apart from each other reduced tillering, apparently due to lower R:FR ratio sensed by the phytochrome system.

INTRODUCTION

Dryland cropping systems of the Texas High Plains are characterized by limited precipitation and high evaporative demand (Stewart and Burnett, 1987) due to high radiation, wind speed, vapor pressure deficit, and temperature. Grain sorghum, with special characteristics to adapt and grow under dryland conditions, is a major crop in the Texas High Plains. Grain sorghum yield in dryland cropping systems of the High Plains is largely dependent on availability of stored soil water at the time of planting (Unger and Baumhardt, 1990), planting date (Stewart and Steiner, 1990), planting density (Stewart and Steiner, 1990), planting geometry and effective utilization of solar radiation (Steiner, 1986). Sorghum often has adequate water from precipitation and stored soil moisture early in the season, and produces one to several tillers leading to high amounts of aboveground biomass and leaf area. However, severe stress conditions are common during later growth stages of the crop and result in failure for many tillers to produce heads, or result in small heads with small kernels. Agronomic studies conducted during 2002 to 2004 at Bushland, TX and during 2004 at Tribune, KS revealed that planting grain sorghum in clumps produced fewer tillers and increased yields when compared to uniformly spaced plants under water stress conditions (Bandaru, 2005). However, the optimal spacing and geometry needed to grow grain sorghum plants clumps in order to decrease tillers was unclear. Also, the mechanisms that led to a decrease in the number of tillers formed when grain sorghum was grown in clumps were not well-understood. Jones (1985) reported that reduced plant competition for light, nutrients and water favors tiller production, whereas low temperature and short day lengths result in fewer tillers in grain sorghum. Jackson and Thomas (1997) found that phytochrome *A* (long day plants) and Phytochrome *C* (short day plants) are responsible for daylight sensitivity. Gautier et al. (1999) showed that red/far-red (R:FR) light ratio regulates tillering in perennial grasses and a reduction in R:FR ratio decreases tillering. Monaco and Briske (2000) showed that in a perennial grass species a low R:FR ratio is involved in shade avoidance response that in some part of the growth cycle result in increased plant height.

The hypothesis of this study was that plants grown in clumps would increase plant height and decrease number of tillers due to a low R:FR ratio of incident light sensed by the phytochrome system. The specific objectives were to evaluate 1) how close together plants need to be in clumps to reduce tillering, 2) the number of plants needed in a clump to reduce tillering, and 3) light and temperature differences associated with tillering patterns of sorghum grown in clumps compared with uniformly spaced plants.

MATERIALS AND METHODS

Two experiments were conducted at the Texas Agricultural Experiment Station, Bushland, TX (35°11'N, 102°5'W) during 2005. A randomized split-plot design was used in both experiments with three replications. Two hybrids ─ Pioneer 8699 and NC+ 5C35 were tested as the main plot treatments in both experiments. Four planting geometries and four plant densities were tested as the subplot treatments in two experiments. The data were analyzed using SAS (Statistical Analysis System) software (SAS, 1998) using General Linear Model procedure (PROC GLM).

Experiment I

Equal plant populations of 5.3 plants m^{-2} were maintained in 75-cm rows. All four planting geometries had four plants for every meter of rows. The four planting geometries were 1) adjacent clump with four plants seeded close to each other (AC); 2) loose clump with four plants seeded 2.5 cm apart from each other in a square (LC); 3) wide clump with four plants seeded 10 cm apart from each other in a square (WC); and 4) four individual plants seeded as uniformly spaced plants 25 cm apart in 75-cm rows (USP). The rows ran east to west and plots were 6 m long and 3 m wide. Planting occurred on July 13, 2005 using a mechanical hand planter for the AC and USP treatments. The LC and WC treatment were planted manually using a pattern cut out of cloth with holes to dibble the seeds by hand. Two seeds more than the desired number of plants were dropped 5 cm deep in to the soil and emerged plants were later thinned to establish equal plant populations. The germination was not uniform due to poor soil moisture conditions at the time of seeding.

Experiment II

Four planting densities in clump planting geometry were tested as subplot treatments. One plant, two plants, four plants, and six plants were established close to each other in clumps 75 cm apart from each other in 75-cm rows. Therefore, for every 0.56 m^2 there were one, two, four or six plants (1.8 plants m^{-2}, 3.6 plants m^{-2}, 7.1 plants m^{-2}, and 10.7 plants m^{-2}). Rows ran east to west and plots were 3 m long and 2.25 m wide to accommodate 12 clumps in each plot.

Measurements taken

Similar measurements were taken in both the experiments on the same dates. Specific plants were randomly identified in all plots to assess growth and development. Plant growth stages ranging from emergence to physiological maturity were identified and numbered from 0 to 9 (Vanderlip, 1993). Up to growth point differentiation, phenology was measured on the basis of leaf number. Later, flag leaf emergence, booting, half bloom and full bloom were recorded as measures of phenology. A tiller was counted after visibly emerged from the leaf sheath. Visibility of leaf collar was used to count the leaf number until emergence of flag leaf. Later, only physiologically active leaves were counted. Plant height was measured from the base of the plant (at the soil surface) to tip of the tallest leaf. Light reflectance was measured 28 days after planting (DAP) using a hyperspectral radiometer. The sensor was focused on the base of the plants to measure the amount of reflected light. Later in the growing season (37 DAP), incident light was measured with a Skye 660/730 nm sensor. The wavelengths of red and far-red light were measured in micromole m^{-2} sec^{-1} $microamp^{-1}$ ($\mu mol\ m^{-2}\ s^{-1}\ \mu A^{-1}$) (Skye Instruments, 2005). The red and far-red light measurements were used to calculate the red to far-red (R:FR) ratio. Two sensors were used to measure light at each plant. One sensor was placed vertically close to the plant stem in the shaded region, and the other sensor was held in the open sun near the plant base. The distance of the sensor placed in the sunlight was varied from 2.5 cm to 15 cm to avoid shade from leaves and neighboring plants. Measurements were taken in the open sunlight by moving the sensor away from the plant up to 30 cm and consistent readings were recorded. Stem temperatures were measured with an infrared thermometer aimed at the base of the stalk and leaf temperatures at the canopy level. Light and temperature measurements were taken from 08:00 h to 18:00 h on 37 and 59 days after planting. Grain yields were not obtained because of damage caused by birds.

RESULTS AND DISCUSSION

The growing conditions early in the season were unfavorable due to delay and uneven distribution of precipitation. Although 280 mm of precipitation was received in 2005 prior to planting the grain sorghum, distribution was poor and planting had to be delayed until 13 July because of inappropriate soil moisture in the topsoil. However, abundant supply of stored water deeper in the soil profile coupled with about 100 mm of evenly distributed precipitation after emergence resulted in favorable growing conditions and there was no visible water stress during the growing season.

Experiment I

At 12 DAP the plants in clumps were further developed than the plants in rows (Fig. 1). Growth stages measurements (1.0 – three leaf stage; 1.5 – four leaf stage; 2.0 – five leaf stage; 4.0 – flag leaf stage; 5.0 – booting stage; 5.5 – heading stage; 6.0 – half-bloom stage) for plants in the AC (1.5), LC (1.5), and WC (1.4) treatments indicated that they were very close to, or at, the four-leaf stage. In contrast, plants in the uniformly spaced rows were at 1.27 (in between three and four-leaf stage) growth stage. However, hybrids were not significantly ($P>F=0.05$) different at 12 DAP, but at 51 and 59 DAP the hybrids were significantly different. At 51 DAP

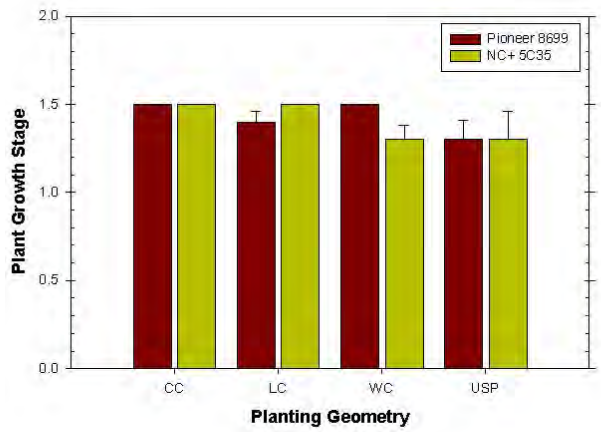

Fig. 1. Plant growth stage (0.5–two leaf stage, 1.0–three leaf stage, 1.5–four leaf stage) by planting geometry and hybrid (12 DAP). Lines on the bars represent standard error.

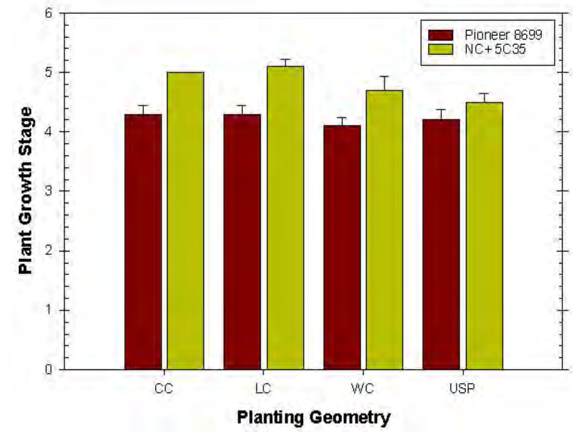

Fig. 2. Plant growth stage (4–flag leaf stage, 5–Booting stage, 5.5–heading stage) by planting geometry and hybrid (51 DAP). Lines on the bars represent standard error.

(Fig. 2) NC+ 5C35 (4.8 - near booting stage) was further developed than Pioneer 8699 (4.2 - at flag leaf stage). Also, plants in LC were further developed (4.7) than those in WC (4.4). At 59 DAP, NC+ 5C35 plants were near the full bloom stage (6.3) but Pioneer 8699 plants (5.7) had not reached the half-bloom stage. At 20 and 28 DAP, there was a trend for AC and LC treatments to have fewer tillers than the WC and USP treatments, but the differences were not statistically significant (P>0.05). However, at 51 DAP (Fig. 3), plants close to each other in clumps (AC and LC treatments) had significantly fewer tillers than those in the USP treatment. Plants close to each other (AC and LC) had about one tiller each. In contrast, plants that were 25 cm apart in rows (USP) had 2 tillers plant^{-1} .

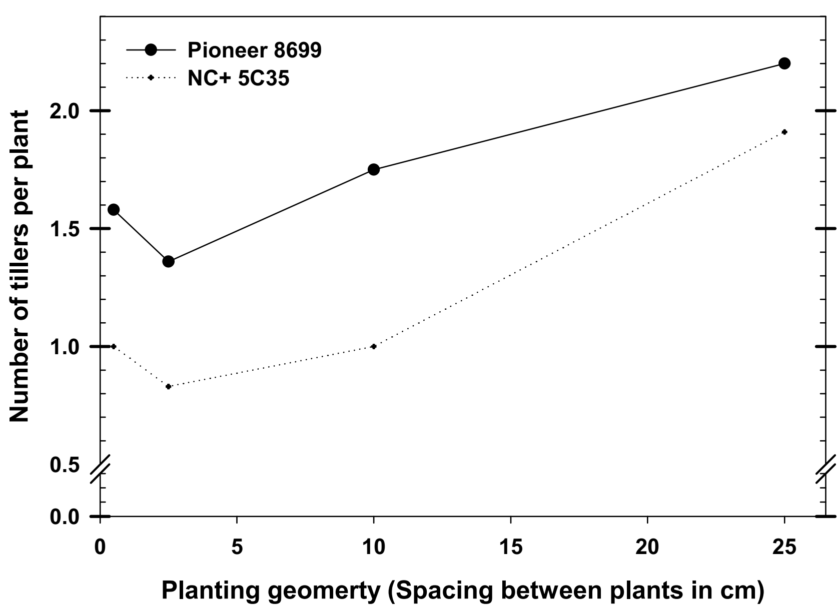

Fig. 3. Tiller number by planting geometry and hybrid (51 DAP).

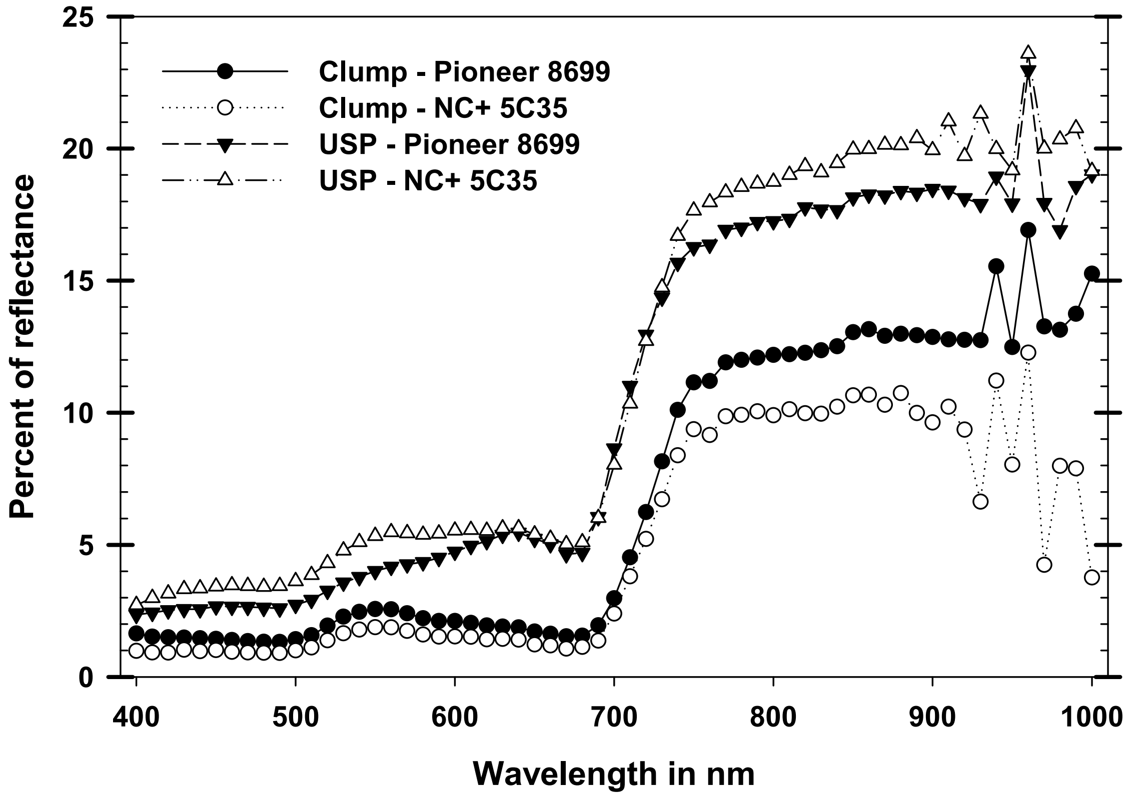

Fig. 4. Light reflected (14 DAP) by clump and USP geometries for two hybrids.

At 71 DAP the tiller numbers were similar to those at 51 DAP and Pioneer 8699 plants had an average of 1.7 tillers plant^{-1} (average of all treatments) compared to an average of 1.2 for NC+ 5C35 plants. Reflected light measured by a hyperspectral radiometer for plants in AC and USP treatments for two hybrids are presented in Fig. 4. The plants in USP rows reflected higher amount of light when compared to USP. The R:FR ratio for the plants in USP treatment was higher than the plants in AC treatment.

For most of the day, the R:FR ratio of incident light at 37 DAP on the sunlit side of the plants averaged 0.99 compared to 0.31 for the shaded side. These values are similar to those reported by Deregibus et al. (1985) for measurements above and below the canopy of forage grass. At 13:00 h 37 DAP the R:FR ratio on the shaded side for the plants in the LC treatment was 0.19 compared to 0.22 for plants in the AC treatment (Fig. 5). In contrast, a higher R:FR ratio of 0.26 was measured for plants in the WC and USP treatments. The amount of light (R:FR) received was not significantly different (P>F=0.05) among hybrids.

The R:FR ratio decreased as the plants grew in closer proximity to one another because of mutual shading. The amount of incident light reaching the site of tiller formation (base of the plants) was lower and resulted in production of fewer tillers. These findings agree with those of Deregibus et al. (1985).

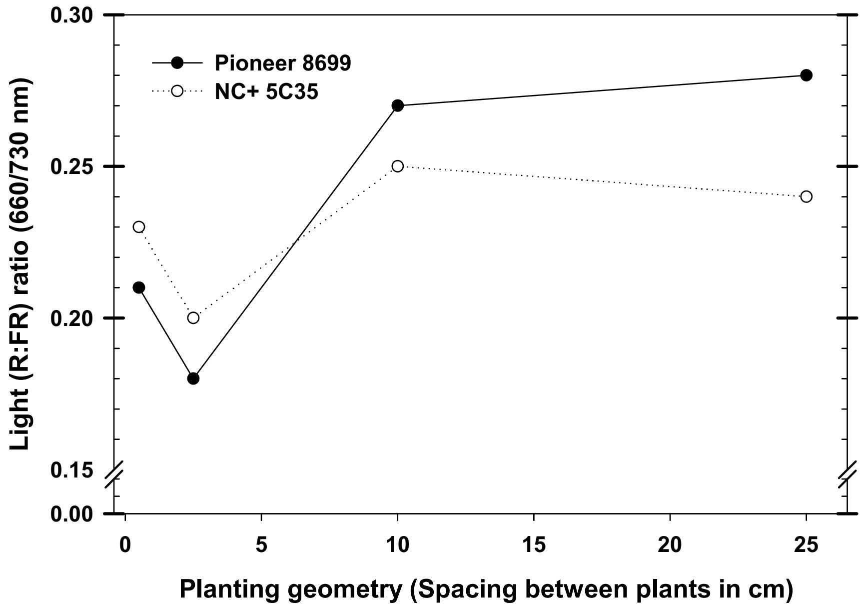

Fig. 5. Light (R:FR) ratio by planting geometry and hybrid (37 DAP).

There was no treatment effect on plant temperature (data not shown). This was apparently due to the absence of water stress because of near adequate soil moisture conditions throughout the cropping season. The number of leaves plant^{-1} and plant heights were similar for all treatments.

Experiment II

The time periods for reaching various plant growth stages were affected by the four different plant densities used in the study. There were differences between the hybrids with NC+ 5C35 at more advanced stages of developing than Pioneer 8699 at 51 and 59 DAP. At 59 DAP, Pioneer 8699 was between heading and half-bloom (5.7) whereas NC+ 5C35 was between half-bloom and full-bloom stage (6.2). Leaf counts of physiologically active leaves revealed interesting details with differences between hybrids and plant densities in the study. At 20 DAP, the main stalks in single plants had more leaves per plant (6.7) than clumps with two plants (5.9 leaves) or six (5.7 leaves) plants. The trend was similar at 59 and 72 DAP with Pioneer 8699 plants having more leaves than NC+ 5C35 plants. Craufurd et al. (1993) reported that leaf appearance reduced under water stress conditions and as the stress was severe, the leaf appearance was completely ceased. At 72 DAP (Fig. 6), single plants (9.2) and clumps with two plants (8.8) had more leaves plant^{-1} than clumps with four plants (7.9) and six plants (7.8). With increase in plant density there was a decrease in plant available water. It was also observed that plants in clumps with four or six plants matured faster than those with two plants or single plants. Plant heights measured at 51 DAP were not statistically different (P>F=0.05) for various densities.

Tiller numbers decreased with increases in planting density, as summarized in Table 1 for four planting densities, two hybrids and four different dates after planting. At 20 DAP, clumps withtwo plants and single plants had 1 and 2 tillers plant^{-1} respectively. In contrast, clumps with four plants averaged 0.6 tillers plant^{-1} and clumps with six plants averaged only 0.3 tillers plant^{-1}. This trend was consistent at 28 DAP, 51 DAP and 72 DAP indicating that with the increase in

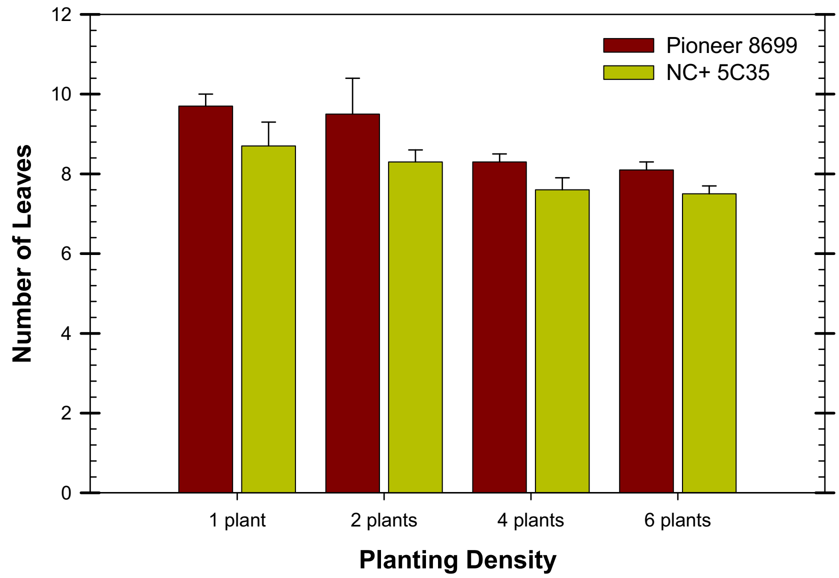

Fig. 6. Leaf number by plant density and hybrid (72 DAP).

Table 1. Number of tillers (mean values) as influenced by planting density and variety

Hybrid→	Number of tillers plant^{-1} for Pioneer 8699				Number of tillers plant^{-1} for NC+ 5C35			
Treatment	20 DAP	28 DAP	51 DAP	72 DAP	20 DAP	28 DAP	51 DAP	72 DAP
1 Plant by itself	2.3 c	2.7 c	2.7 c	3.0 c	2.0 c	2.3 c	4.0 c	6.0 c
2 plants in clump	1.3 b	1.5 b	1.5 b	1.5 b	1.2 b	1.5 b	1.7 b	2.3 b
4 plants in clump	0.6 a	1.0 a	0.9 a	0.9 a	0.6 a	0.7 a	0.6 a	0.6 a
6 plants in clump	0.3 a	0.7 a	0.6 a	0.6 a	0.3 a	0.4 a	0.3 a	0.5 a

Means followed by same letter are not significantly (*P*>F=0.05) different using LSD.
DAP – Days after planting.

plant density the tiller number plant^{-1} decreased. These results are similar to those by Casal et al. (1986) who found that the number of tillers per plants in grasses decreased with increase in plant density.

The incident light ratio (R:FR) decreased consistently with increased number of plants in clumps. The light ratios measured in the shade of the plant base at 13:00 h on 37 DAP are presented in Fig. 7. At 37 DAP the R:FR ratio at the base of a single plant was 0.33 and was significantly (*P*>F=0.05) higher than the ratio at the base of clumps with four plants (0.20) and six plants (0.20). Additionally, clumps with two plants sensed light with a higher R:FR ratio (0.28) than clumps with four and six plants (0.20). The results for R:FR ratios at 59 DAP were consistent with those at 37 DAP indicating that R:FR ratio decreases with increases in plant density.

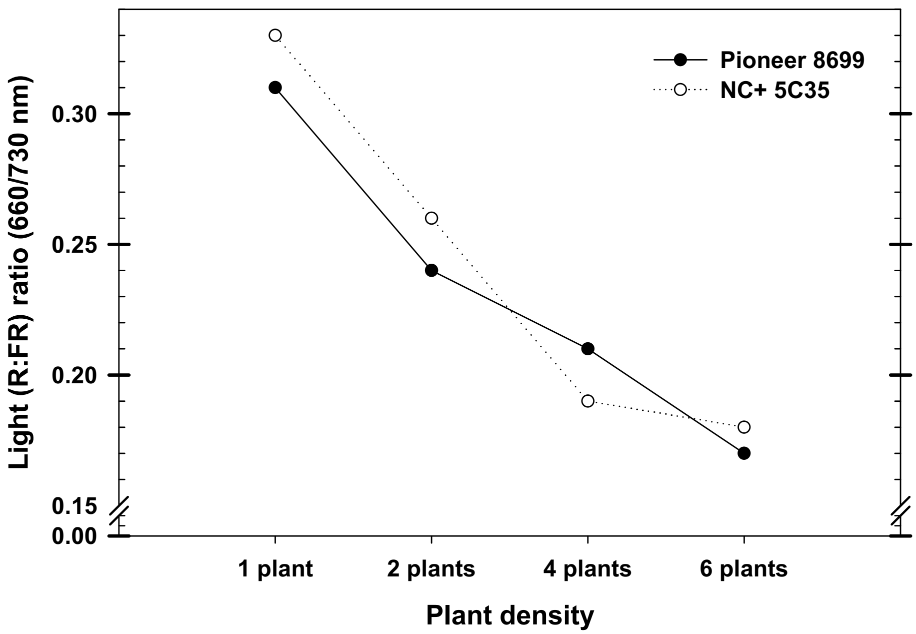

Fig. 7. Light (R:FR) ratio by planting geometry and hybrid (37 DAP).

CONCLUSIONS

Our results provide additional evidence and a clear understanding about the effect that planting dryland grain sorghum in clumps has on decreasing the number of tillers produced. Under our dryland conditions tillers are more often than not "excessive baggage" that results in much of the stored soil water being depleted during vegetative growth stages leading to severe water stress during the reproductive and grain filling stages. When grain sorghum was planted in clumps of four plants close to each other (2.5 cm or less apart), mutual shading resulted in lower R:FR ratios at the base of the plants and in fewer tillers plant^{-1}. The R:FR ratio and number of tillers plant^{-1} decreased with increased plant density and decreased spacing between the plants in the clumps. Apart from reducing tiller number, plants in clumps were observed to develop faster and had a change in architecture. Clumped plants adapted to environmental conditions by altering the number of leaves, and leaves tended to grow upward in contrast to outward for uniformly spaced plants. Additional study is needed to why these changes occurred and what physiological processes governed them.

ACKNOWLEDGMENTS

The authors are thankful to the Texas Water Development Board for partial funding of this research and to Dr. Mustafa Mirik for his assistance in using hyperspectral radiometer and to Dr. Arden Collette for assistance in data analysis. The authors also extend thanks to Prabhakar Konda, Kadasrivenkata Hanumantharao, Srinivas Veeragoni, Shivakumara Bheemappa, Nagendra Earle and Tebkow Belete for their valuable and timely assistance in fieldwork.

REFERENCES

Bandaru, V. 2005. Response of dryland grain sorghum to planting geometry. M.S. thesis. West Texas A&M Univ., Canyon, TX.

Casal, J.J., R.A. Sanchez, and V.A. Deregibus. 1986. The effects of plant density on tillering: the involvement of R/FR ratio and the proportion of radiation intercepted per plant. Environ Expl Bot. Vol. 26. 4:365-371.

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

Deregibus, V.A., R.A. Sanchez, J.J. Casal, and M.J. Trlica. 1985. Tillering responses to enrichment of red light beneath the canopy in humid natural grassland. J. Applied Ecol. 22:199-206.

Guatier, H., C.V. Grancher, and L. Hazard. 1999. Tillering responses to the light environment and to defoliation in populations of perennial ryegrass (*Lolium perenne* L.) selected for contrasting leaf length. Ann. Bot. 83:423-429.

Jackson, H., and B. Thomas. 1997. Photoreceptors and signals in the photoperiodic control of development. Plant, Cell Environment 20:790-795.

Jones, A.C. 1985. C_4 grasses and cereals. Growth, development and stress responses. p. 80-82.

Monaco, T.A., and D.D. Briske. 2000. Does resource availability modulate shade avoidance response to the ratio of red to far-red radiation? An assessment of radiation quantity and soil volume. New Phytol. 146:37-46.

Skye Instruments Inc. 2005. Instruments for environmental monitoring, plant and agricultural research, crop sciences. Skye Instruments Ltd., 21, Ddale Enterprise Park, Llandrindad Wells, Powy, LD1 6DF.

SAS Institute. 1998. SAS/STAT user guide. Release 6.3. SAS Ins., Cary, NC.

Steiner, J.L. 1986. Dryland grain sorghum water use, light interception, and growth responses to planting geometry. Agron. J. 78:720-726.

Stewart, B.A., and E. Burnett. 1987. Water conservation technology in rainfed and dryland agriculture. p. 355-359. *In* W.R. Jordan (ed.) Water and water policy in world food supplies. Texas A&M Univ. press. College Station, TX.

Stewart, B.A., and J.L. Steiner. 1990. Water use efficiency. p. 151-173. *In* R.P. Singh, J.F. Parr and B.A. Stewart (eds.) Advances Soil Sci. Vol.13. Springer and Verlag, NY.

Unger, P.W., and R.L. Baumhardt. 1999. Factors related to dryland grain sorghum yield increases: 1939 through 1997. Agron. J. 91:870-875.

Vanderlip, R.L. 1993. How a sorghum plant develops. Kansas State Univ. Manhattan, KS.