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Effect of Defoliation at Different Stages on Grain Sorghum Yield and Yield Components

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Summary

Loss of leaf area usually results in yield loss in grain crops, but the amount of yield loss varies with extent and timing of defoliation. Grass crops, such as corn and grain sorghum, are particularly sensitive to leaf area loss near the time of seed set because there is little opportunity for the plant to compensate. An experiment to quantify yield reductions associated with various levels of defoliation imposed at different stages of grain sorghum development was conducted at Manhattan, KS, in 2023. Target defoliations of 0, 33, 66, and 100% were imposed at 5-leaf, flag leaf appearance, half bloom, and hard dough stages. Defoliation of 5-leaf sorghum resulted in minimal yield loss unless the defoliation rate was 100%, which delayed heading, increased heads per plant, and reduced head size. Leaf area losses approaching 100% at the hard dough stage caused minimal yield reductions in a year with high temperatures and minimal rainfall during grain fill. Yield reductions were greatest when leaf area was lost at flag leaf appearance or half bloom. Leaf area loss of 60% or greater caused yield losses of 40% to 70%. These yield losses were associated with different combinations of reductions in head size and seed size depending on timing of leaf loss.

Introduction

Leaves are the primary source of energy for growth and grain filling in grain sorghum. Although dry matter is translocated from the stem to grain during grain filling, leaf area is required to deposit that dry matter in the stems. Of several possible causes, hail damage tends to cause the greatest loss of leaf area on a field level and can be eligible for compensation via crop insurance. Usually, greater leaf area loss is associated with greater yield loss. However, that relationship changes as the sorghum crop develops. Leaf loss early in the season usually causes minimal yield loss because the lost leaf area is a relatively small fraction of the total. Leaves that emerge after defoliation may support near normal seed set and grain fill. Leaf loss late in the season may cause minimal yield loss because grain fill has neared completion, and dry matter translocation from stems may compensate for the loss of new photosynthate. However, leaf area losses near the time of seed set are likely to cause the largest yield losses in sorghum and other grass crops because most of the leaf area has already emerged, and grain fill has just started. These relationships have been characterized in the past, but the response of modern sorghum hybrids in contemporary production systems is lacking. The objective of this experiment was to characterize the response of a modern grain sorghum hybrid to varying levels of leaf loss at different stages of crop development.

Procedures

Experiment Site and Agronomic Management

The experiment was located at Manhattan, KS, on a Kahola silt loam soil. Sorghum hybrid P84P72 was planted on April 27, 2023, at 75,000 seeds per acre using a White 9000 series planter with Precision Planting seed meters and 20|20 seed monitoring system. Fertilizer was applied before planting as a mix of 28% UAN and ammonium polyphosphate to supply 112 pounds of nitrogen and 55 pounds of P_2O_5 per acre. A mix of burndown and residual herbicides was applied before crop emergence on May 3. Plots were harvested on September 21–26 after reaching physiological maturity.

Treatments and Experimental Design

Treatments consisted of four levels of defoliation imposed at four developmental stages. The target defoliation levels were 0, 33, 66, and 100% and were imposed using a cordless hedge trimmer plus hand trimming the 100% treatment as needed. The sorghum stages when defoliations were imposed were S2 (5 leaves fully emerged), S4 (flag leaf visible in whorl), S6 (half bloom), and S8 (early hard dough). All treatments were arranged in a randomized complete block experimental design with five replications.

Data Collection and Analysis

Immediately after each defoliation, plants were clipped from a 3-foot section of row. Samples were refrigerated until processed to determine leaf area using a LiCor LI3100C area meter. Actual defoliation rate was calculated as the leaf area remaining immediately after defoliation as a percent of the 0% defoliation plots in each replication. Leaf area index (LAI) was calculated by dividing the sample leaf area by the sample soil surface area. Percent canopy coverage of the soil surface was estimated using the Canopeo app immediately after the S2 and S4 defoliations. Days to half bloom was the number of days from planting until at least half the plants in the center two rows of each plot displayed anthers at least half-way down the head. The number of plants per acre was determined by counting all plants in the center two rows of each plot at sorghum stage S1 (3 leaves fully emerged) and dividing by the plot area in acres. The number of heads per plant was determined by dividing the number of heads per acre (counted at harvest) by the number of plants per acre. Seed size was determined by weighing 300 seeds. The number of seeds per head was calculated using the mass of grain, head number, and seed size. Grain yield was calculated by dividing the mass of grain by the harvest area and converted to bushels per acre. Effect of defoliation was characterized by regressing days to half bloom, yield components, and yield on measured defoliation rate separately for each developmental stage. Pearson correlation coefficients were calculated for all combinations of variables to characterize relationships between variables.

Results

Growing Season Conditions

Temperatures and precipitation patterns during the 2023 growing season likely affected sorghum's response to defoliation. Daily temperatures and cumulative precipitation were not far from the 30-year normals through early June (Figure 1). Temperatures continued near or below normal through most of July, but precipitation began to lag in mid-June. By the end of September, growing season precipitation was more than 10 inches below normal. Temperatures exceeded normal for several consecutive days in late July, immediately after the S6 defoliation, and again for seven days in mid-August, soon after the S8 defoliation. The combination of below-normal precipitation with periods of intense heat likely shortened grain fill duration and contributed to late-season losses in leaf area observed in plots that had not been defoliated.

Effect of Defoliation on Remaining Leaf Area, Bloom Date, and Plant Height

Increasing rates of defoliation were significantly negatively correlated with LAI and canopy coverage across all developmental stages and within each stage when defoliation was imposed (Table 1). The most severe rates of defoliation at S2 delayed half bloom, but defoliations imposed at later stages had no effect on half bloom (Table 1, Figure 2). Plant height was not influenced by defoliation at S2, S6, and S8, but was strongly reduced as defoliation increased at S4 (Table 1, Figure 3).

Effect of Defoliation on Yield Components and Yield

Defoliation affected yield components differently depending on the developmental stage when the defoliation was imposed. Plant density was not affected by defoliation rate at any growth stage (Table 1, Figure 4). Defoliation at S6 had a minimal effect on heads per plant, but high rates of defoliation at S2 and S8 increased the number of heads per plant, and minimal defoliation at S4 increased the number of heads per plant (Table 1, Figure 5). Head size decreased with greater defoliation at S2, S4, and S6 (Table 1), with the largest decreases when defoliated at S4 (Figure 6). Defoliation at S4, S6, and S8 decreased seed size (Table 1). Seed size decreased linearly with increasing defoliation at S6, but high rates of defoliation at S4 were required to reduce seed size substantially (Figure 7). Seed size was reduced only slightly with the most severe defoliations at S8. Defoliations at S2, S4, and S6 were strongly negatively correlated with grain yield (Table 1) with the most severe yield reductions resulting from defoliation at S4 followed by S6 (Figure 8). Only the most severe defoliation at S2 affected yield, with reductions approaching 40%. Although severe defoliation at S8 reduced seed size slightly (Figure 7), yield was not reduced significantly (Figure 8).

Relationships Among Sorghum Response Variables

Plant density was negatively correlated with number of heads per plant at S4 and days to half bloom at S8, but density was positively correlated with yield at S8 (Table 1). Days to half bloom was not correlated with any other response variable at S4 or S6. At S2, days to half bloom was strongly positively correlated with defoliation rate and heads per plant, and strongly negatively correlated with head size, LAI at defoliation, Canopeo at defoliation, and grain yield. At S8, days to half bloom was positively correlated with plant height and heads per plant and negatively correlated with plant density. Heads per plant was positively correlated with days to half bloom and seed size for defoliations at S2 but had negative correlations with measures of leaf area and the other yield components for defoliations at S4. Defoliation at S6 had little impact on heads per plant. Head size was negatively correlated with defoliation, measures of leaf area, and yield components at S2 and S4 but showed minimal correlation to other variables other than defoliation rate at S6. Head size was negatively correlated with yield for defoliations at S2 and S4 but positively correlated with yield for defoliations at S6 and S8. Seed size had minimal correlation with other variables for defoliations at S2, negative correlation with heads per plant for defoliations at S8 and S4, and strong positive correlations with measures of leaf area at S6.

Yield was strongly, positively correlated with LAI and canopy cover at the time of defoliation for all defoliation timings, but relationships between yield and the various yield components varied with timing of defoliation (Table 1). For defoliations at S2, yield was negatively correlated with days to bloom but positively correlated with head size. For defoliations imposed at S4, yield was negatively correlated with heads per plant, but had strong positive correlations with the other yield components and plant height. For defoliations at S6, yield was strongly positively correlated with head size and seed size, but at S8 positive correlations existed between yield and plants per acre and head size.

Conclusion

Defoliation tended to reduce yield, but the degree of yield reduction varied with timing and extent of defoliation. The greatest yield reductions resulted from severe defoliations at S4 and S6, resulting in yield reductions of 70% and 60%, respectively. Yield reductions were associated with smaller heads and seeds, although the plants tried to compensate by increasing heads per plant with defoliation at S4. Light to moderate defoliations at S2 resulted in minimal yield reduction, likely because the plants could add leaf area and additional productive heads when defoliated at this stage. Severe defoliation at S2 delayed heading and reduced seed set and yield by 40% and 30%, respectively. Yield reductions were minimal with defoliations at S8 and were associated with reductions in seed size. Hot, dry conditions during seed fill likely reduced the impact of the S8 defoliation because grain fill finished soon after that defoliation.

Acknowledgments

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Table 1. Pearson correlation coefficients for defoliation of grain sorghum at Manhattan, KS, 2022

	Defoliation	Days bloom	Plant height	Plant density	Heads/ plant	Head size	Seed size	LAI[1]	Canopeo[2]	Yield
		↓ stage 4 (flag leaf appearance, upper right) ↓								
Defoliation		0.09	**-0.77**	-0.14	**0.46**	**-0.87**	**-0.75**	**-1.00**	**-0.95**	**-0.94**
Days bloom	**0.84**		0.20	0.07	0.00	-0.27	0.11	-0.11	-0.10	-0.17
Plant height	0.01	0.09		0.11	**-0.54**	**0.67**	**0.83**	**0.77**	**0.76**	**0.79**
Plant density	-0.04	0.02	0.07		**-0.46**	0.15	-0.03	0.12	0.09	0.08
Heads/plant	**0.50**	**0.54**	0.33	**-0.54**		**-0.68**	**-0.47**	**-0.46**	**-0.45**	**-0.52**
Seed size	**-0.74**	**-0.77**	-0.24	-0.27	**-0.45**		**0.64**	**0.87**	**0.83**	**0.93**
Seed size	-0.01	-0.13	0.15	**0.45**	-0.33	-0.40		**0.75**	**0.64**	**0.81**
LAI	**-0.99**	**-0.84**	-0.00	0.05	**-0.49**	**0.74**	-0.00		**0.67**	**0.94**
Canopeo	**-0.94**	**-0.88**	0.19	0.11	**-0.51**	**0.67**	0.30	**0.94**		**0.87**
Yield	**-0.78**	**-0.90**	0.02	-0.19	-0.43	**0.81**	0.11	**0.79**	**0.86**	
	↑ stage 2 (five leaves emerged, lower left) ↑									
		↓ stage 8 (hard dough, upper right) ↓								
Defoliation		0.06	0.10	-0.00	0.39	0.07	**-0.53**	**-0.99**	--	0.29
Days bloom	-0.04		**0.51**	**-0.57**	**0.59**	-0.43	-0.25	-0.08	--	-0.43
Plant height	0.15	0.07		-0.29	0.34	-0.15	-0.18	-0.07	--	-0.20
Plant density	0.02	0.07	0.41		-0.38	0.32	0.03	0.04	--	**0.45**
Heads/plant	-0.03	-0.01	-0.14	**-0.70**		-0.44	**-0.54**	-0.40	--	-0.23
Head size	**-0.73**	-0.07	-0.25	-0.01	-0.29		-0.21	-0.06	--	**0.68**
Seed size	**-0.90**	0.23	-0.16	0.07	-0.08	**0.60**		**0.52**	--	0.21
LAI	**-1.00**	0.04	-0.17	-0.02	0.00	**0.76**	**0.90**		--	0.07
Canopeo	--	--	--	--	--	--	--	--	--	--
Yield	**-0.95**	0.06	-0.23	-0.09	0.05	**0.85**	**0.87**	**0.95**	--	
	↑ stage 6 (half bloom, lower left) ↑									
		↓ over all stages (upper right) ↓								
Defoliation		0.44	-0.13	-0.00	**0.32**	**-0.53**	**-0.43**	**-0.73**	**-0.68**	**-0.61**
Days bloom			0.12	0.02	**0.44**	**-0.48**	0.05	**-0.32**	**-0.58**	**-0.32**
Plant height				0.14	-0.18	**0.32**	0.25	0.01	-0.07	**0.40**
Plant density					**-0.46**	0.02	0.15	-0.08	-0.14	0.04
Heads/plant						**-0.51**	-0.18	**-0.28**	**-0.38**	**-0.24**
Head size							0.12	**0.29**	0.26	**0.82**
Seed size								**0.30**	0.11	**0.58**
LAI									**0.95**	0.31
Canopeo										0.18

[1]LAI = leaf area index.
[2]Estimate of % ground cover using the Canopeo App.
Bold values indicate 95% confidence of significant correlation.

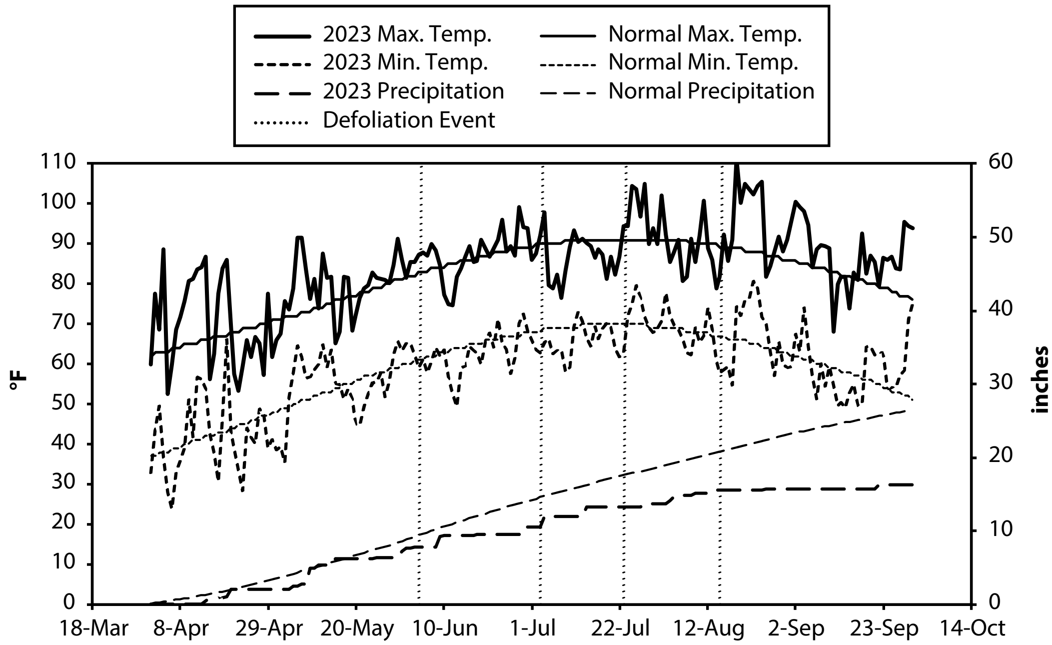

Figure 1. Daily maximum and minimum temperatures and cumulative precipitation for 2023 and 30-year normals for Manhattan, KS. Vertical dotted lines represent defoliation events.

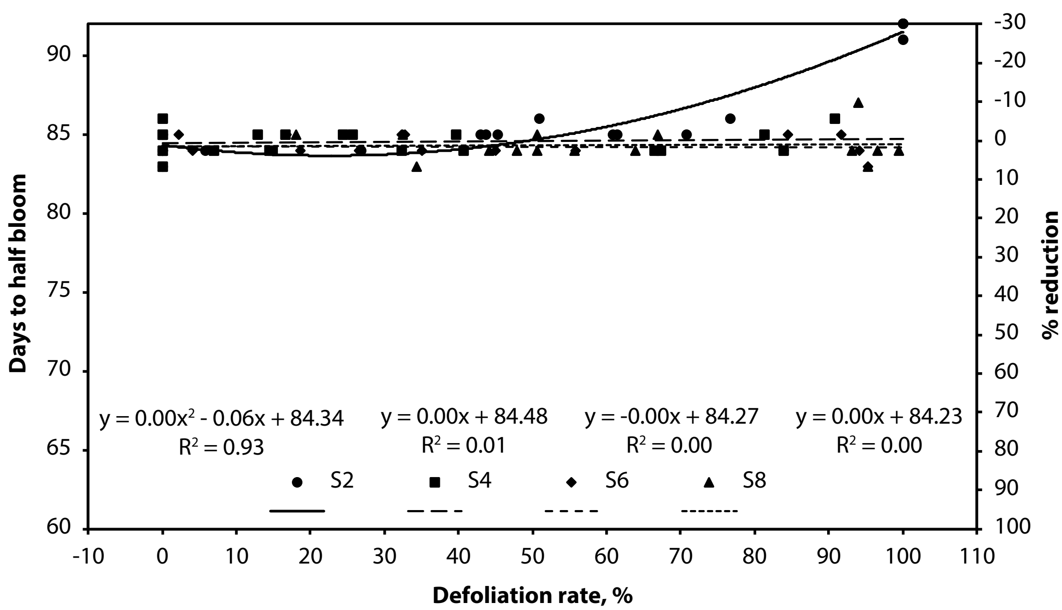

Figure 2. Effect of defoliation at four grain sorghum developmental stages on days to half bloom at Manhattan, KS, in 2023.

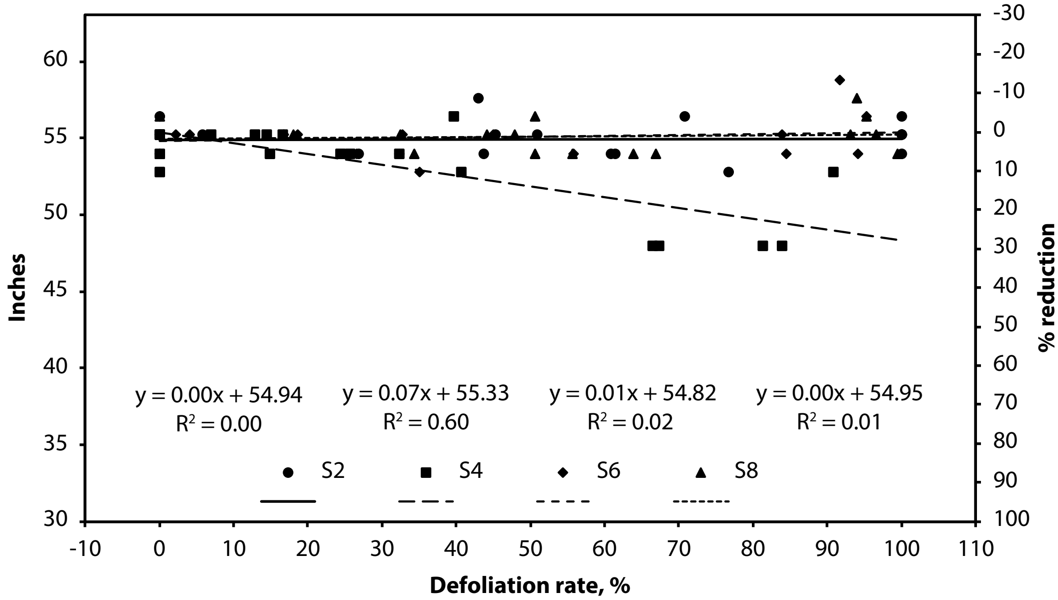

Figure 3. Effect of defoliation at four grain sorghum developmental stages on plant height at Manhattan, KS, in 2023.

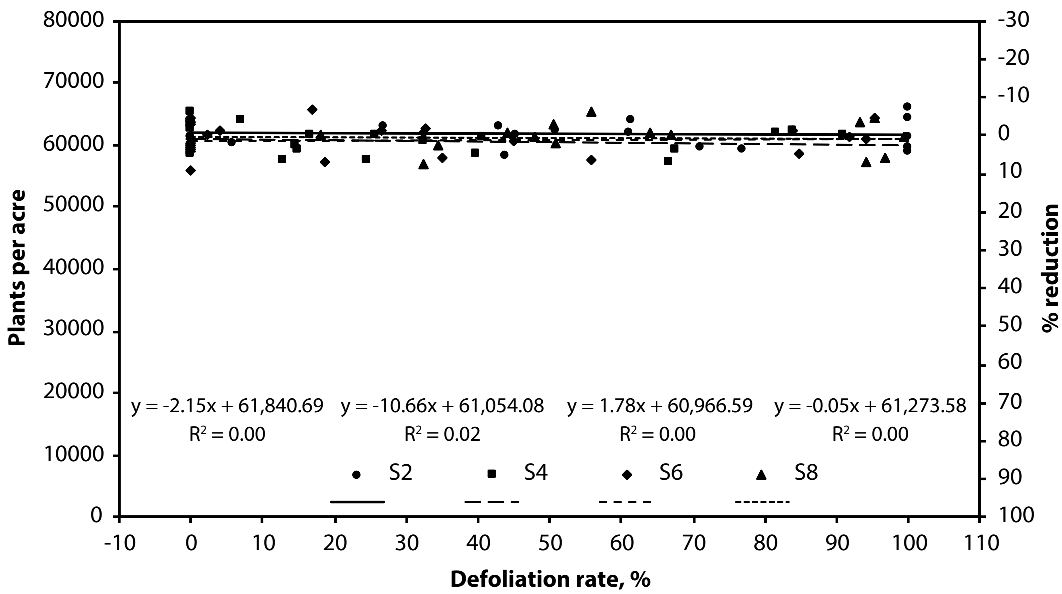

Figure 4. Effect of defoliation at four grain sorghum developmental stages on plant density at Manhattan, KS, in 2023.

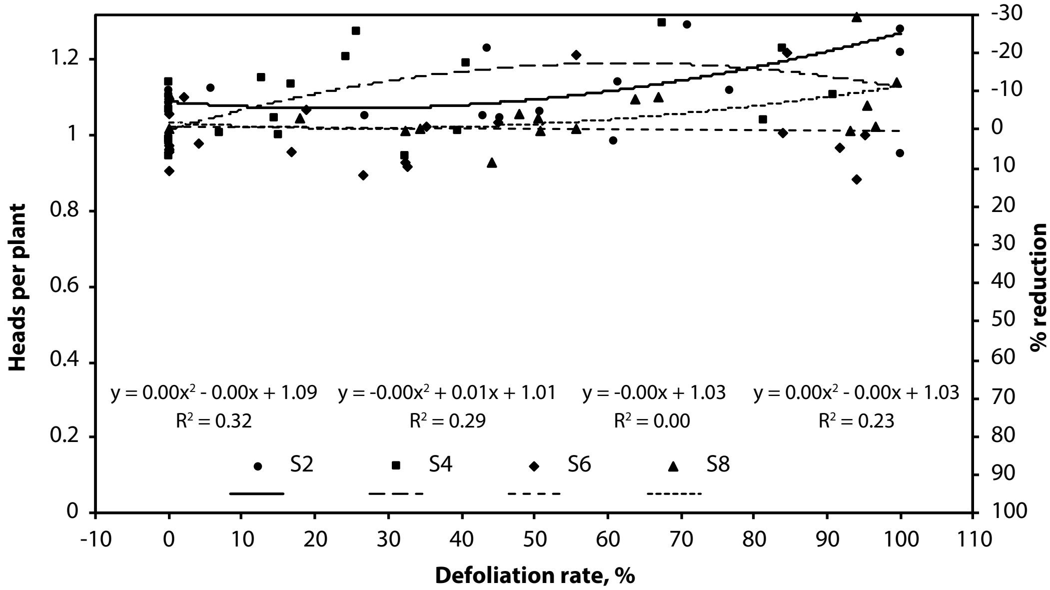

Figure 5. Effect of defoliation at four grain sorghum developmental stages on number of heads per plant at Manhattan, KS, in 2023.

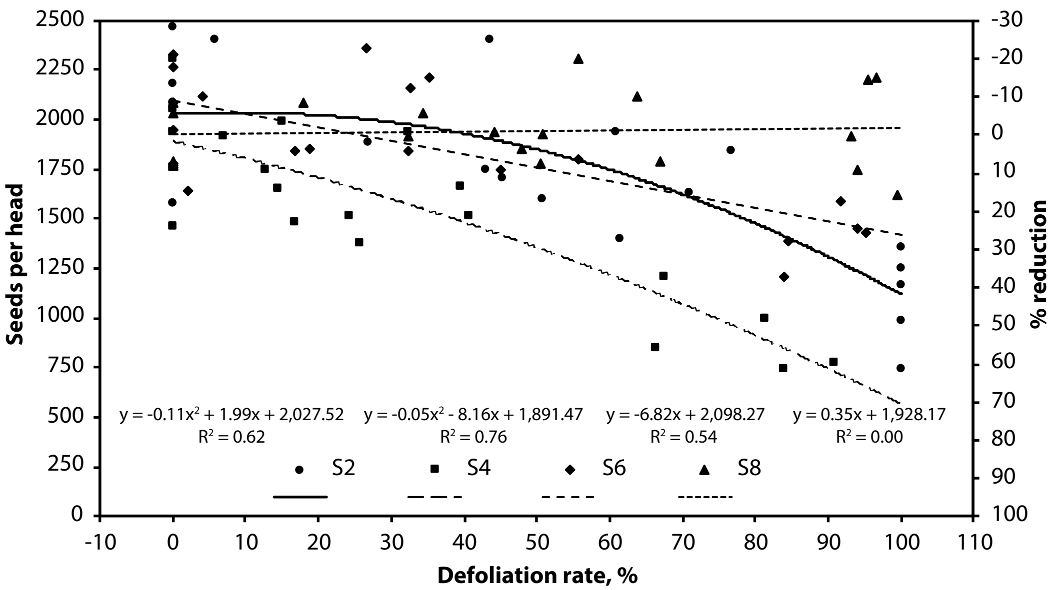

Figure 6. Effect of defoliation at four grain sorghum developmental stages on head size at Manhattan, KS, in 2023.

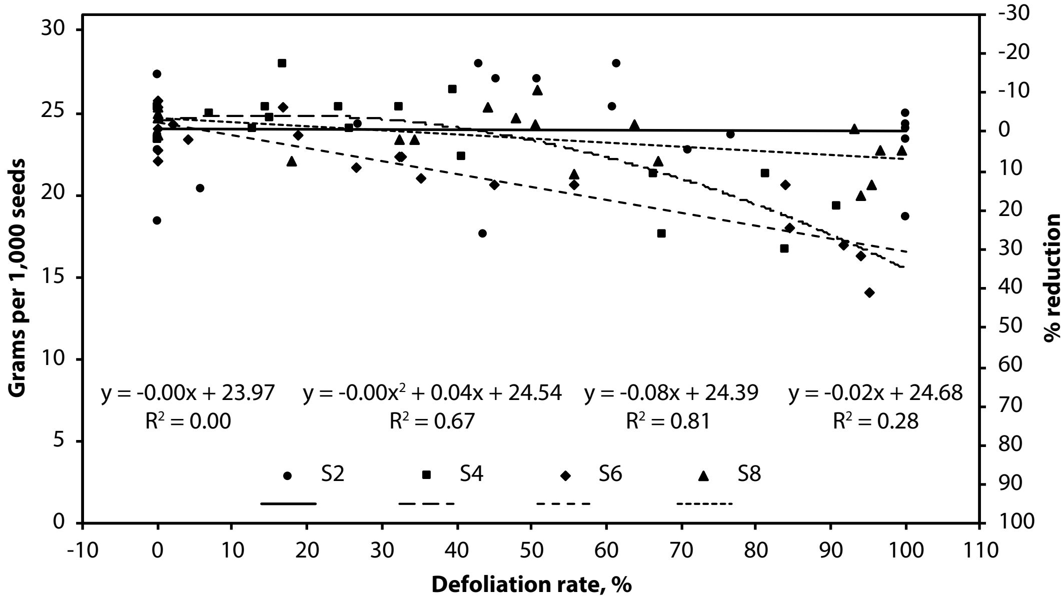

Figure 7. Effect of defoliation at four grain sorghum developmental stages on seed size at Manhattan, KS, in 2023.

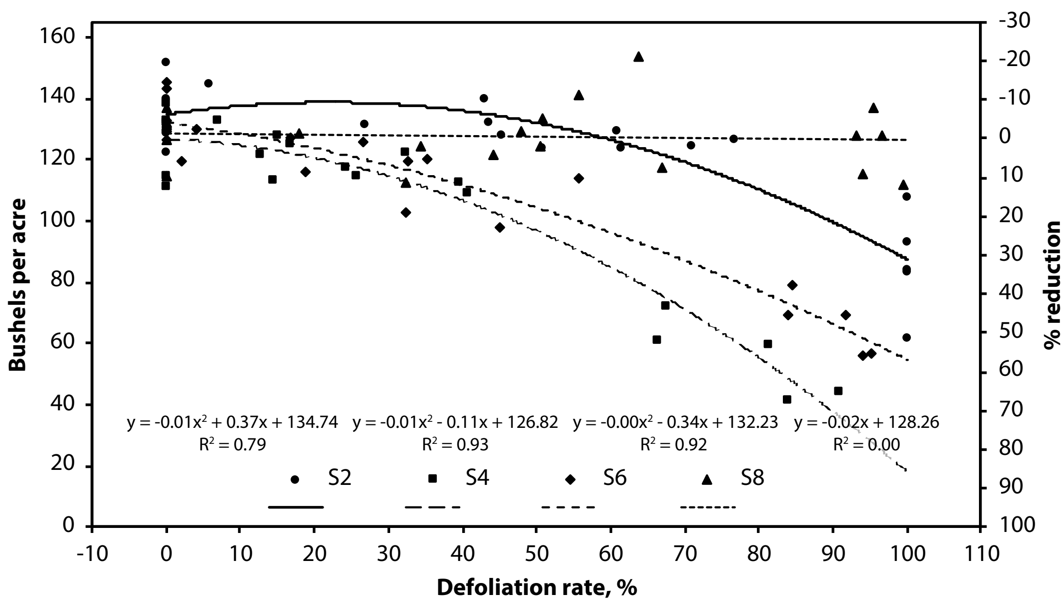

Figure 8. Effect of defoliation at four grain sorghum developmental stages on grain yield at Manhattan, KS, in 2023.