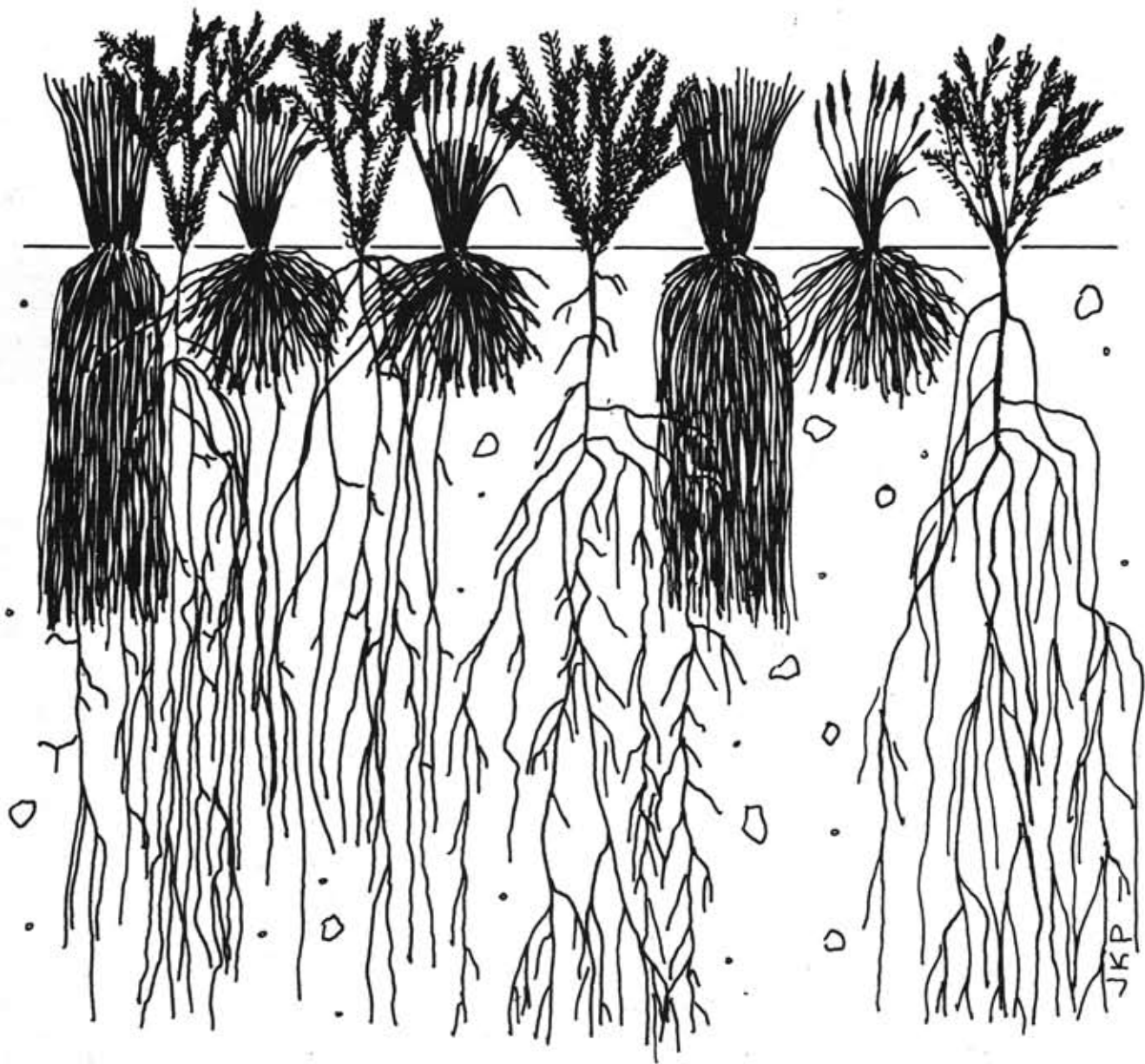


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PROGRESS TOWARD BREEDING A PERENNIAL GRAIN SORGHUM

BROOKS ANDERSON

Abstract. We are investigating the feasibility of creating a perennial sorghum by transferring the overwintering underground stem structure produced by Johnsongrass (*Sorghum halepense*) to its domesticated relative, *S. bicolor*. This year our objectives were to grow out the first generation backcross, and to cross individuals from this backcross back to *S. bicolor* to create a second backcross generation. We then grew both of these backcrosses in the field along with the original F_1 hybrids created in 1986. This field planting was used to observe phenotypic variability for characteristics between generations and between crosses representing seven different *S. halepense* parents.

In the first and second backcross generations the hybrids recovered many of the desirable characteristics of the domesticated parent. Traits such as panicle compactness, stalk strength, and seed yield of the backcrosses were much more similar to the traits of *S. bicolor* than to the traits of *S. halepense*. Many plants in the second backcross generation resembled the *S. bicolor* parent in overall stature and panicle configuration. Furthermore, 70 % of these individuals produced rhizomes.

INTRODUCTION

The most compelling reason for developing a perennial sorghum is the potential it could have for conserving fuel, water, and soil by reducing the need for annual tillage of soil. At The Land Institute, we are interested in perennial sorghum because of the part it could play in polycultures of perennial seed crops. Such polycultures might include other grain-producing warm- and cool-season grasses with legumes to provide nitrogen for other plants in the mixture. Perennial sorghum could play an important role in cropping patterns of the future as our agricultural practices shift from being highly resource intensive to ones that are more ecologically sound, using nature as the standard.

To breed perennial sorghum we are using a tetraploid variety of *S. bicolor* (L.) Moench that resembles the milo widely grown throughout Kansas. *Sorghum bicolor* is weakly perennial in tropical climates but cannot survive freezing temperatures. We are crossing *S. bicolor* with a weedy relative, *S. halepense* L. Pers, known commonly as Johnsongrass, a pernicious weed in North America. It is capable of overwintering because of its thick rhizomes (underground stems). Because Johnsongrass is tetraploid, we are using a tetraploid variety of *S. bicolor* to increase fertility of the hybrids. The goal of this experiment is to develop a cultivar with the general morphology of *S. bicolor* and rhizomes of *S. halepense*.

The parents we are using possess strongly contrasting physical characteristics. Most of the characteristics we desire are from the cultivated parent. These include high seed yield, uniformity of height, strong stalks, compact heads, large seeds, few stalks, short stature, and resistance to shattering. From the *S. halepense* parent we are most interested in rhizomes. Its loose heads, tendency to shatter seeds upon maturation, thin stalks, height, and small seed size make Johnsongrass undesirable as a seed crop. Furthermore, the seeds of Johnsongrass are enclosed in glumes, some being totally encapsulated, which makes threshing the seed of Johnsongrass very difficult. Glumes of *S. bicolor* are small in proportion to seed size. Other than rhizomes, the only other *S. halepense* trait we would like to transfer to our hybrid is its tendency to fully exert its panicles from the boot, or highest leaf which wraps around the panicle as it develops. In our tetraploid *S. bicolor* parents exertion from the boot is poor, resulting in reduced seed yield.

We would like to transfer both of these traits, rhizome produc-

tion and positive head exertion, to a hybrid cultivar, but not to the degree we find them expressed in the weed parent. Johnsongrass spreads and multiplies profusely by rhizomes because each node produced is capable of becoming a new shoot. *Sorghum halepense* can produce 60 to 90 m of rhizomes per plant in a single growing season (McWhorter 1973). If this tendency were transferred in its entirety we would have developed a weedy cultivar. Instead, we would like to transfer an amount of rhizomes sufficient to overwinter and maintain the population at a constant density over several years.

Our effort to develop a hybrid perennial sorghum began in 1983 when the original crosses were made between domesticated sorghum and Johnsongrass. In 1985, the F_2 generations from these crosses were grown in the field and scored for a variety of characteristics including dwarfing, seed size, seed yield, and configuration of the head. The success of these crosses indicated that there were no major barriers to recombination between *S. bicolor* and *S. halepense* (Braun 1985). In 1986, The Land Institute acquired through Kansas State University ten lines of tetraploid *S. bicolor* which were more agronomically desirable than earlier varieties. These were crossed with 17 accessions of *S. halepense* collected from Kansas, Oklahoma, and California (Reinhart 1986). These F_1 hybrids were self-pollinated to create an F_2 generation in the greenhouse over the winter of 1986-87. In 1987, F_1 and F_2 generations from ten crosses were grown in pots in the field with parental plants to observe variability for 22 characteristics (Kulakow and Ennis 1988). Because the frequency of desirable plants was very low in the F_2 generation, F_1 hybrids representing 14 of the *S. halepense* parents were crossed back to the *S. bicolor* parents in 1988. This created the first backcross generation of hybrids (BC_1) which possess 75 % genetic material from the domesticated parent and 25 % from the weed parent (Delisle 1988).

This year our objectives were to grow out the BC_1 generation, cross BC_1 to the *S. bicolor* parent to create a second backcross (BC_2), and grow these two generations in the field to observe variation between and within generations and among crosses involving seven *S. halepense* parents. Primarily we were interested in learning to what extent rhizomes would be produced in the first and second backcross generations and how seed yield and agronomic suitability might be affected. We expected plants with more *S. bicolor* genes to exhibit more strongly the characteristics of the domesticated parent and, correspondingly, to possess fewer rhi-

zomes than the previous generation.

MATERIALS AND METHODS

Although the original crosses and first backcrosses used several tetraploid *S. bicolor* parental lines, there was sufficient variation in flowering time among the cultivated parents to suggest that poor adaptation due to late flowering was coming from the cultivated parent. In February 1989, we planted BC₁F₁ seeds representing eight *S. halepense* parents. We crossed these plants to emasculated panicles of the selected early flowering *S. bicolor* parent to create the BC₂F₁ generation.

On 16 June, four generations of crosses, designated BC₀F₁, BC₁F₁, BC₁F₂, and BC₂F₁, representing seven *S. halepense* parents were planted in the field (Figure 1). The planting was arranged in a replications within groups design (Shutz and Cockerham 1966), with seven groups representing the seven *S. halepense* parents. Within each group there were five replication of fourteen plants. Each replication contained one BC₀F₁, one BC₁F₁, two BC₂F₁, and ten BC₁F₂ plants. The field site was a Tobin silt loam soil with a 0-2% south-facing slope. Plants were established as single plant hills spaced 91 cm apart in each direction. Single shoots of the BC₀F₁ and BC₁F₁ plants were transplanted from greenhouse grown plants. BC₁F₂ and BC₂F₁ plants were seeded in hills and thinned to one plant per hill. Irrigation was limited to watering of transplants to aid initial establishment. Despite low rainfall, overall establishment was successful. We weeded the field as needed by tractor and hand cultivation mainly to control field bindweed (*Convolvulus arvensis* L.).

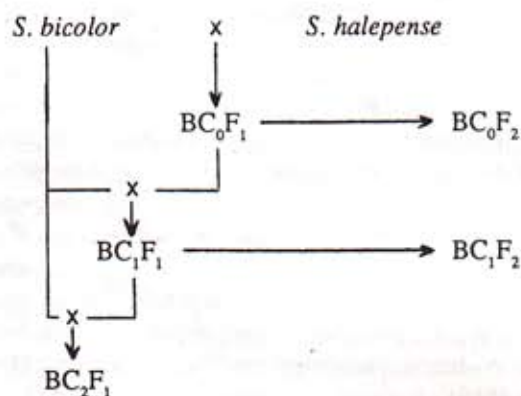


Figure 1. Diagram of the crossing history of *S. bicolor* x *S. halepense* crosses and backcrosses at The Land Institute.

The plants were observed throughout their development. We recorded the date each plant began to flower and measured 16 physical attributes on mature plants (Table 1). Such characteristics as compactness of the panicle and stalk strength were scored visually on a qualitative spectrum with the opposite ends representing the two parents. To measure seed yield, we harvested the earliest flowering panicle from each plant. One or two later panicles from each plant were bagged to insure self-pollination. After a killing frost, we excavated plants to examine them for rhizome production. If rhizomes were present we recorded the number of rhizomes and the total number of rhizome nodes produced. Late maturing

plants from two blocks were left in the field to test for overwintering ability.

After measuring and excavating the plants, we analyzed and summarized the data by comparing the means, sorting, and interpreting generational trend.

RESULTS

Our purpose was to determine the appropriate number of times to backcross hybrids between the annual and perennial sorghum back to the cultivated parent while retaining their ability to produce winter-hardy rhizomes. In the field planting this year, the various ratios of genetic material from the cultivated and weed parents were clearly visible. Each time a hybrid was crossed back to the *S. bicolor* parent its progeny more strongly resembled the domesticated parent. This observation was validated by analysis of measurements taken on the 16 characteristics listed in Table 1.

Table 1. Characteristics scored on *Sorghum bicolor*-*S. halepense* crosses.

Quantitative	Qualitative
leaf length (cm)	stalk strength
leaf width (cm)	head compactness
leaf number	head erectness
plant height (cm)	shattering
internode length (cm)	
reproductive culm number	
head length (cm)	
head width (cm)	
seed weight (g)	
rhizome presence	
rhizome number	
rhizome node number	

We were most interested in the trends in seed yield and rhizome production over the four generations and between the seven crosses involving different *S. halepense* parents. Time of flowering determined when a plant would be measured. Mean number of days to flowering decreased from the BC₀F₁ to BC₂F₁ generation. In the BC₀F₁ generation, 38% of the 34 plants bloomed too late to yield mature seed. In the BC₁F₁ generation, 29% of 35 plants were too late. By the BC₂ generation, only 14% of 50 plants were too late. The frequency of late plants varied among the groups. Late flowering plants were not harvested due to a killing frost in mid-September.

Trends in generation means: Recovery of *S. bicolor* traits

Despite variation in plant development, we observed several trends that occurred across generations in all seven of the experimental blocks. As we progressed from the BC₀F₁ to the BC₂F₁ generation, means for most traits approached those of the cultivated parent (Table 2). For example, mean plant height in the BC₀F₁ was 199.6 cm versus 157.3 cm for the BC₁F₁, 99.9 cm for the BC₂F₁, and 82 cm for the *S. bicolor* parent. Similarly, culm number decreased from 11.6 in BC₀F₁, to 5.1 in BC₂F₁, and 4.5 in *S. bicolor*. Leaves were much shorter after each backcross, with the BC₀F₁

averaging 73.5 cm, the BC₁F₁ averaging 69.5 cm, the BC₂F₁ averaging 61.5 cm, and *S. bicolor* averaging 52.5 cm.

We made progress recovering other desirable traits such as stalk strength and resistance to seed shattering. Nine percent of the BC₀F₁ plants had strong seed stalks, whereas 33 % had stalks resembling those of *S. halepense*. In the BC₁F₁, 46 % of the stalks were strong and only 11 % were undesirable. By the BC₂ generation, 60 % of the plants had strong stalks resembling *S. bicolor*, and only 2 % had flimsy stalks. In the BC₀F₁, only 29 % of the plants were non-shattering and 57 % were highly shattering. By the BC₂F₁ generation, 93 % of the plants were scored as non-shattering and none were highly shattering.

The shape, size, and desirability of the heads changed over generations as the percentage of cultivated genes increased in the hybrids. In the BC₀F₁ generation, no plants received a desirable score for compactness of the panicle, whereas 94 % of the plants resembled *S. halepense*. In the BC₁F₁, 12 % received a compactness rating of 4, with 5 representing a typical cultivated panicle. In the BC₂F₁, 24 % of the heads were scored as 4 and 13 % were scored as 5, meaning that they were very compact and desirable. Although head size decreased from the BC₀F₁ to the BC₂F₁ generation, heads remained on average 35 % wider and 23 % longer than *S. bicolor* heads in the BC₂F₁ generation.

Similar trends in rhizome production and seed yield were discernible across generations. Plants of the BC₀F₁ generation produced a mean of 11 rhizomes, with a total of 30.7 rhizome nodes per plant. In the BC₁F₁, these decreased to 9.5 rhizomes and 20.9 nodes. By the BC₂F₁ generation, the plants produced an average of 4.2 rhizomes and 6.1 nodes. The number of nodes per rhizome declined from 2.9 in the BC₀F₁ to 1.4 in the BC₂F₁. Although 70 % of the plants in the BC₂F₁ produced rhizomes, they produced only 38 % as many rhizomes and only 20 % as many rhizome nodes as did the BC₀F₁.

As the number of rhizomes decreased over generations, seed yield increased from the BC₀F₁ to BC₂F₁. The mean seed weight of the BC₀F₁ was 11.7 g per panicle. This doubled in the BC₂F₁ to a yield of 23.3 g seed per panicle (Table 2).

In the BC₁F₂, inbreeding depression was evident in some characteristics compared with the BC₁F₁. The average plant height in the BC₁F₁ generation was 157.3 cm. This decreased to 116.5 cm in the BC₁F₂ from self-pollinated BC₁F₁ plants. Culm number also decreased from 7.2 in the BC₁F₁ to 5.8 in the BC₁F₂ generation. Rhizome expression acted similarly, with rhizome number decreasing in six of the seven crosses. From the BC₁F₁ to the BC₁F₂, average number of rhizomes decreased from 9.5 to 5.6, and number of rhizome nodes decreased from 20.9 to 10.1.

Variability among crosses

Although generational trends commonly occurred in all seven groups or crosses with different *S. halepense* parents, we observed variability among the crosses. Mean seed weight per panicle in Group 2 was 6.5 g in the BC₀F₁ generation, whereas in Group 4 the mean yield was 20.1 g. In the BC₂F₁ generation, plants in Group 3 yielded an average of 15.3 g, whereas plants in Group 7 yielded 42.9 g.

Much of the variability among crosses occurred in rhizome node production. In the BC₀F₁ generation, Group 1 produced a mean of 3.4 nodes whereas Group 6 produced a mean of 67.3 nodes. This range was reflected in the number of rhizomes produced in the BC₀F₁ generation, with plants in Group 1 producing 3.2 rhizomes

Table 2. Means (\pm s.d.) and ranges for several agronomic traits in *S. bicolor* parental and backcross generations.

	Plant height (cm)		
	N	Mean	Range
BC ₀ F ₁	21	199.6 \pm 46.5	134-286
BC ₁ F ₁	25	157.3 \pm 43.7	109-270
BC ₁ F ₂	179	116.5 \pm 30.9	47-185
BC ₂ F ₁	43	99.9 \pm 22.5	48-146
<i>S. bicolor</i>	10	82.0 \pm 10.7	61- 95
	Seed weight (g)		
	N	Mean	Range
BC ₀ F ₁	18	11.7 \pm 7.9	0-34.2
BC ₁ F ₁	23	17.1 \pm 17.2	0-55.8
BC ₁ F ₂	148	17.7 \pm 13.7	0-57.3
BC ₂ F ₁	34	23.3 \pm 15.0	1.2-56.9
<i>S. bicolor</i>	10	23.0 \pm 7.0	6.3-29.5
	Culm number		
	N	Mean	Range
BC ₀ F ₁	34	11.6 \pm 7.1	3-27
BC ₁ F ₁	35	7.2 \pm 2.8	1-15
BC ₁ F ₂	338	5.8 \pm 2.3	2-17
BC ₂ F ₁	50	5.1 \pm 1.2	3- 8
<i>S. bicolor</i>	10	4.5 \pm 0.9	3- 6
	Rhizome number		
	N	Mean	Range
BC ₀ F ₁	31	11.0 \pm 7.5	1-34
BC ₁ F ₁	31	9.5 \pm 6.5	1-33
BC ₁ F ₂	256	5.6 \pm 3.7	1-21
BC ₂ F ₁	39	4.2 \pm 2.4	1-10
	Rhizome node number		
	N	Mean	Range
BC ₀ F ₁	31	30.7 \pm 25.6	2-90
BC ₁ F ₁	31	20.9 \pm 20.2	1-92
BC ₁ F ₂	256	10.1 \pm 9.0	1-75
BC ₂ F ₁	39	6.1 \pm 4.5	1-18

and Group 6 producing 20.7 rhizomes. By the BC₂F₁ generation, number of rhizomes ranged from 3.0 in Group 1 to 6.2 in Group 5. Variability within crosses decreased from the BC₀F₁ to BC₂F₁ generation as traits became fixed by an increasing proportion of *S.*

DISCUSSION

The potential indicated here for developing a hybrid perennial grain sorghum that is similar to *S. bicolor* in most respects and can also produce rhizomes is encouraging. The short stature, large seed and head size, high yield, and stalk strength of the BC₂F₁ hybrid is an improvement over the BC₀F₁ and BC₀F₂ hybrids used in 1987. In 1987, only 2.4 % of the BC₀F₂ plants were judged desirable (Kulakow and Ennis 1988), versus 11 % for the BC₁F₂ and 62 % for the BC₂F₁ hybrids in 1989. We do not know if plants at this stage produced adequate rhizomes to ensure overwintering, however. The plants left in the field for evaluation of winter survival in spring 1990 will indicate the quality of the rhizomes produced. Many factors, however, determine the ability to overwinter. These include not only the length of the rhizome, but also its depth, moisture, and thickness (Aldrich 1984). This structure then interacts with the local soil and climate conditions to determine overwintering ability.

The rhizomes produced this year, though comparable in number to those produced in 1987, were not as long. This may cause them to die over the winter. Although a mean of only 2.1 rhizomes were produced on the BC₀F₁ hybrids in 1987, they produced 12 nodes per rhizome. The BC₀F₁ hybrids planted this year in the field produced only 2.9 nodes per rhizome.

The production and growth of rhizomes appears to be influenced by the environment (McWhorter 1972). In the 1987 evaluation, plants were grown outdoors in plastic containers and were fertilized and watered regularly throughout the experiment. This year, the plants were grown in a field that had not been fertilized, and only the transplants were irrigated for initial establishment. Throughout the summer the plot experienced drought stress that may have suppressed rhizome development. During 1987, rhizome production may have been enhanced by regular irrigation and the application of fertilizer. It remains to be seen what rhizome expression would be in field grown plants with normal precipitation. Other evidence of the environmental sensitivity of rhizome production is shown by a comparison between BC₁F₁ plants in the

greenhouse and in the field. In the greenhouse, only 7 % of BC₁F₁ plants produced rhizomes. In the field, 97% of the same generation produced rhizomes, with an average of 20.9 nodes per plant.

Our results this year indicate that one backcross may be all that can be made without losing too much capability for rhizome production. This can be tested by evaluating genotypes from both backcrosses over the winter to test winter survival. Variation in the production of rhizomes due to environmental fluctuation will have to be considered when selecting individual crosses for a large, multi-year field trial. Each plant appears to possess a range of rhizome production potential. The overwintering ability of any genetic individual will probably require testing its progeny in a replicated design due to its probable low heritability. This will need to be explored to avoid developing a cultivar that spreads unexpectedly and undesirably in a year of high rainfall and thereby disrupts the balance within a mixture of perennials or invades areas where it is not intended to be grown.

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