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Selection of morphological traits to improve forage characteristics of *Setaria sphacelata* grown in Florida

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Abstract A genetically diverse population of *Setaria sphacelata* was developed at Gainesville, Florida by intercrossing the cultivars ‘Narok’, ‘Kazungula’ and ‘Solander’ and a local persistent population. To determine heritability of traits that may improve setaria as a forage plant in Florida, progeny of the intercrossed population underwent two cycles of selection for inflorescence number and one cycle for leaf width. The selected populations, together with cultivars and introductions, were evaluated for morphological characters, yield and forage quality in field experiments with close- and wide-spaced plants. Increase of inflorescence number was not obtained by selection but resulted in decreased plant height, inflorescence length, yield, leaf width, and leafiness. Leaf width was increased by selection and was associated with increased leafiness and whole-plant crude protein content. The results suggest good prospects for selection of setaria cultivars

suited to Florida with improved yield and quality providing they tolerate winter cold and reliably produce seed.

Keywords breeding; leaf width; inflorescence number; forage production; forage quality

INTRODUCTION

The forage grass *Setaria sphacelata* (Schumacher) Moss (setaria) has been widely used in medium rainfall subtropical regions as a pasture grass for grazing of dairy and beef cattle, as well as for silage and hay. The species has been recommended for use in tropical and subtropical countries with a minimum yearly rainfall of 750 mm, or 580 mm on very fertile soils (Botha 1948). However, it grows better in wetter areas with no prolonged dry season (Rat-tray 1960), as in the wet zone of Sri Lanka (Assefa & Premaratne 1990), on dairy farms in the humid tropics of Costa Rica (Sanchez et al. 1998), and in Thailand (Hare et al. 1999). Animal performance on setaria pastures can be limited by low rainfall (Jones & Evans 1989).

Setaria has the desirable forage attributes of high yield (Singh et al. 1995), persistence (Gibson & Andrews 1985), high crude protein concentration (Almeida & Flaresso 1991) and good animal performance (Jones & Evans 1989). In southern Brazil, ‘Narok’ setaria was superior to *Hemarthria altissima* for milk production (Martinez 1993), and in Mexico, meat production on ‘Kazungula’ setaria was higher than on *Brachiaria brizantha* pastures (Partida et al. 1983). Recent evaluations have shown that setaria may have forage potential in Florida particularly if selections can be made to ensure winter survival (Jank et al. 2002).

Setaria sphacelata is a polyploid complex ranging from diploid to decaploid (Hacker 1968). The basic chromosome number is $n = 9$. It includes the varieties *sphacelata*, *aurea* (A. Br.) Clayton, *torta* (Stapf) Clayton, *sericea* (Stapf) Clayton, and *splendida* (Stapf) Clayton (Clayton & Renvoize 1982).

There is no clear morphological distinction between these varieties and they readily intercross (Hacker 1968). Of the released cultivars, only 'Nandi' (var. *sericea*) is diploid (Hacker 1966). All the others, 'Kazungula' and 'Narok' (var. *sericea*) and 'Solander' and 'Splenda' (crosses between var. *sericea* and var. *splendida*) are tetraploid (Hacker 1966; Oram 1986).

Setaria is largely cross-pollinating and apomixis has not been reported. Favoured by self-incompatibility, random mating of inflorescences from selected parents has been successful when combined with multiple recurrent selection cycles to enhance the process of plant improvement (Jank et al. 2002). Early breeding focused on *S. sphacelata* var. *sericea* for traits such as forage yield, seed yield and frost tolerance (Jank & Hacker 2003). Later, var. *splendida* was incorporated into the breeding programmes because it is more robust than var. *sericea* and has a higher number of culm nodes, greater culm diameter, wider leaves and is taller and later flowering. The only negative aspects of this introduction was its almost complete sterility (Hacker 1985). Since then, improved seed production was the focus of many breeding programmes (Wijk 1980; Hacker 1991a,b; Hacker & Cuany 1997).

High heritabilities were found for leaf width (Hacker & Bray 1981), inflorescence length, and tiller fertility (Hacker & Cuany 1997), suggesting that these traits can be easily selected. Wide leaves may increase sward density and thus may increase short-term intake by cattle. Inflorescence length and tiller fertility may increase seed production. Leaf width was positively correlated with flower inflorescence number and with dry weight. Selection for increased dry matter yield should result in earlier flowering plants with shorter inflorescences (Hacker & Bray 1981).

A breeding programme of *S. sphacelata* was developed in Gainesville, Florida since 1996, to establish the use of this plant for forage production in the State. A base population was developed from a bulk of seeds of introduced cultivars and a local persistent population, and was evaluated to ensure persistence in Florida. The key factor, tolerance of winter cold, was assessed and proved possible to be improved (Jank et al. 2002). Persistence under grazing in Florida conditions was also ascertained (Paul Mislevy pers. comm.). The next steps in the programme should include the selection of high-yielding, persistent and high quality populations, and ensure the population selected for commercial release can reliably produce seed.

The objectives of this research were to produce advanced populations of *S. sphacelata* selected for morphological traits of agronomic value and to evaluate the effects of this selection on agronomic performance in a common environment. Specific objectives were to increase dry matter yield through selection of wider leafed populations, and increase seed production through selection of higher inflorescence number populations.

MATERIALS AND METHODS

Base population

A population of *S. sphacelata* with a wide genetic base was planted in August 1996 at the Agronomy Forage Research Unit (AFRU) of the University of Florida, near Gainesville, Florida (29°75'N, 82°4'W). Two thousand seedlings were planted on 90 cm centres. The population was a bulk of seeds from 'Narok', 'Kazungula', and 'Solander' and from roadside plants that had persisted for many years at the University of Florida Range Cattle Research and Education Center at Ona, Florida. 'Narok' and 'Solander' were selected in Australia for frost tolerance and are recommended for subtropical areas. 'Kazungula' was selected in South Africa for grazing and hay production and is indicated for more tropical areas (Jank & Hacker 2003). This cultivar is the most widely grown one and the most drought tolerant. It is very productive in summer, but this is associated to high stem and seed production. 'Narok' and 'Solander' are leafier than 'Kazungula' and retain green leaf after light frosts. Seed yield of 'Solander' is twice that of 'Narok' because of double the tiller fertility and number of heads, but still less than 'Kazungula' (Jank & Hacker 2003).

In autumn of 1996, grid selection for autumn vigour was applied to this population. The two or three most vigorous plants in each 25-plant block (five rows of five plants) were selected to provide 200 plants (Fig. 1). Two inflorescences per selected plant were harvested when they were fully extended and before flowers opened to show stigmas or stamens. The inflorescences were cut from the base of the 200 selected plants with roots attached and placed together in a bucket of water in a greenhouse to be intercrossed. They were covered with a large paper bag and shaken twice daily to enhance random pollination. Inflorescences were left in the bucket to mature seed for approximately 25 days to assure that the later flowering florets had time to

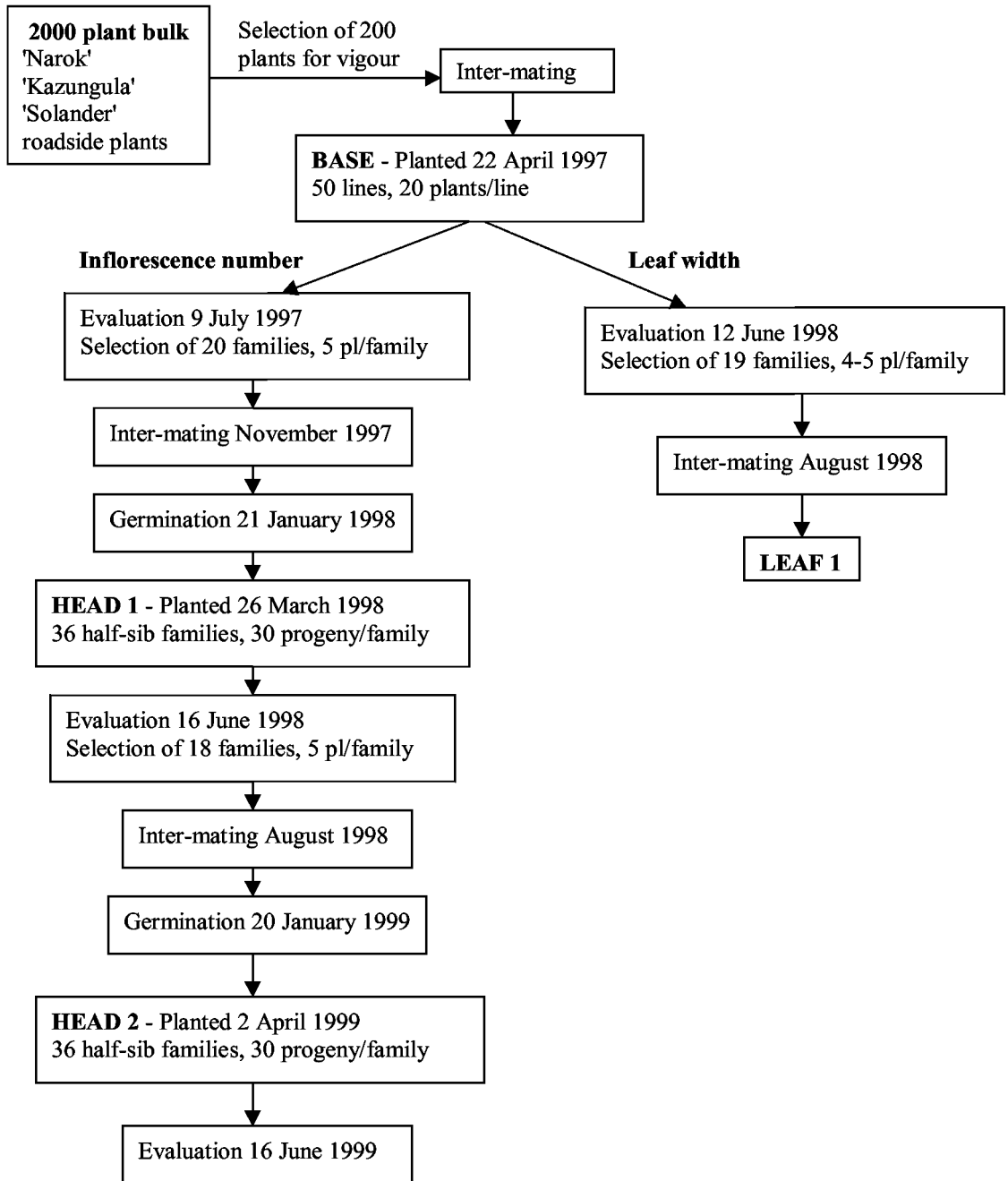


Fig. 1 Flow diagram of the development of BASE and selected populations.

mature into seeds. Mature seeds were harvested per inflorescence and threshed. Seeds were germinated on 19 February 1997, and further selection was made based on number of germinated seedlings in the best 50 lines. This population designated BASE, was the base population for the breeding work. To facilitate comprehension of the development of BASE population and subsequent populations, a flow diagram is presented (Fig. 1). Dates of germination, field planting, and evaluation of BASE and selected populations are given in Table 1.

Population development

Twenty plants of each of the 50 lines of the BASE population were transplanted to the field on 22 April 1997 in two replications of 10 plants each (Fig. 1 and Table 1). On 9 July 1997 the number of inflorescences of these plants were recorded. The number of inflorescences was estimated by grouping inflorescences into groups of 10, counting the number of groups formed, and multiplying by 10. Leaf width was measured on 12 June 1998 in the middle of three fully extended leaves on vegetative culms.

The breeding methodology used was a modification of half-sib family selection with some restrictions suggested by Burton (1982). This involved the

use of detached culms and inter-mating under a large paper bag permitting control of male and female gamete sources in the production of the selected population. Half-sib progeny identification was maintained in the selected population and half-sib families were planted in the next generation. Half-sib family means were determined for the traits of interest and selection in the next generation was based on superior half-sib families. In addition, further selection was conducted by selecting superior individuals within superior families. This methodology has been described as best plants in best families (Nguyen & Sleper 1983).

Selection for inflorescence number

In November 1997, three inflorescences from the five plants with highest inflorescence numbers in each of 20 selected families were harvested for intercrossing in a polycross as described earlier. Threshed seeds of Cycle 1 selected for increased number of inflorescences (HEAD 1) were germinated in flats in the greenhouse on 21 January 1998 (Fig. 1). On 26 March 1998, 36 half-sib families that had more than 30 of the progeny were transplanted to the field on 90 cm centres in a randomised complete block design with two replications of 15 plants each.

Table 1 Means of populations and selections, heritability and expected gains for *Setaria sphacelata* populations selected for increased number of inflorescences and leaf width.

| | Selection cycle | | | |
|-------------------------------------|----------------------------|-------------|-------------|-----------------|
| | Inflorescences/plant (no.) | | | Leaf width (cm) |
| | BASE | HEAD 1 | HEAD 2 | BASE |
| Population | | | | |
| Germination date | 19 Feb 1997 | 21 Jan 1998 | 20 Jan 1999 | 19 Feb 1997 |
| Planting date | 22 Apr 1997 | 26 Mar 1998 | 2 Apr 1999 | 22 Apr 1997 |
| Evaluation date | 9 Jul 1997 | 16 Jun 1998 | 16 Jun 1999 | 12 Jun 1998 |
| Days from germination to evaluation | 140 | 146 | 147 | 478 |
| No. of plants | 1000 | 1080 | 1080 | 1000 |
| No. of families | 50 | 36 | 36 | 50 |
| Family range | 76–147 | 8–48 | 40–124 | 0.8–1.33 |
| Mean \pm SD | 112 \pm 35 | 28 \pm 20 | 70 \pm 28 | 1.0 \pm 0.2 |
| Selection | | | | |
| No. of selected plants | 100 | 90 | 85 | 78 |
| Mean of selected plants | 162 | 60 | 112 | 1.3 |
| No. of selected families | 20 | 18 | 17 | 19 |
| Selected family range | 113–147 | 28–48 | 70–124 | 1.0–1.3 |
| Heritability [†] | 0.37 | 0.51 | 0.74 | 0.59 |
| Expected gain | 130 | 44 | 101 | 1.2 |
| Expected gain (%) | 16 | 57 | 43 | 18 |

[†]Heritability estimated on an individual plant basis.

On 16 June 1998 the number of inflorescences per plant was recorded. Eighteen families were selected, and as with the previous cycle, the five plants with highest number of inflorescences within each selected family were harvested and intercrossed in a greenhouse.

Threshed seeds of Cycle 2 were germinated in a greenhouse on 20 January 1999 (Fig. 1). On 2 April 1999 the 36 half-sib families of Cycle 2 (HEAD 2) with more than 30 progeny were planted in the field in the same layout as Cycle 1. On 16 June 1999 the number of inflorescences per plant was counted to obtain data for trait variability and calculation of heritability estimates for an additional cycle. Seventeen families and 78 plants were selected (Table 1).

Selection for leaf width

Breeding for increased width of leaves was conducted by harvesting five inflorescences from the five widest-leaved plants in each of 19 selected half-sib families in the BASE population. Seeds harvested from the polycross became leaf width Cycle 1 (LEAF 1) (Fig. 1).

Heritability estimates were calculated on an individual plant basis according to Nguyen & Sleper (1983). Genetic gain was calculated according to Falconer & Mackay (1996).

Population comparisons

The populations selected for increased inflorescence number (HEAD 1 and HEAD 2), and the population selected for increased leaf width (LEAF 1) were compared in two experiments, a wide-spacing and a close-spacing experiment. The experiments were planted at the AFRU on 26 July 1999 with seedlings grown from seed of the three populations. The soil type was Pomona sand (sandy, siliceous, hyperthermic Ultic Alaquods) fertilised with 25 kg N ha⁻¹ at planting and irrigated.

Wide-spacing experiment

In the wide-spacing experiment, 64 seedlings of the populations HEAD 1, HEAD 2, LEAF 1, BASE and variety 'Solander' were transplanted to the field on 26 July 1999 in a randomised block design with four replications. The plots consisted of four rows of four plants each spaced 90 cm between rows and plants. In September 1999 the plants were evaluated for leaf width, inflorescence length, and number of inflorescences as described before. Canopy height was measured from the soil surface to the height where most leaves reached their maximum height. Culm height

was measured from the soil surface to the average top of the inflorescences. Inflorescence length was recorded as the mean of five inflorescences. When seeds were mature, seed production was evaluated. Three inflorescences of each of 16 plants in a replication were harvested and combined, threshed, and analysed for purity by running seeds in an air column seed blower to separate filled caryopses from empty caryopses and other debris. Data were analysed with Proc GLM of SAS (SAS Institute 1989).

Close-spacing experiment

In the close-spacing experiment, seedlings of populations HEAD 1, HEAD 2, LEAF 1, and BASE, and as standards the cultivars 'Solander' and 'Splenda' and the plant introductions 'Fenwicks' (CPI 33452), and 'Thompson Falls' (CPI 33453), were transplanted to the field on 26 July 1999 in a randomised complete block design with three replications. The four standards were received from the Australian Tropical Forages Genetic Resource Center (ATF-GRC). 'Fenwicks' is a tetraploid from Kenya, and has shown an intermediate degree of frost tolerance in Australia. 'Thompson Falls' is a hexaploid from the high altitude Aberdares region in Kenya, and was tolerant to frost in Australia (Hacker 1972).

Plots were five rows of 12 plants each spaced 30 cm between rows and plants. Plots were harvested on 2 September and 13 October 1999 and fertilised with 25 kg N ha⁻¹ after each cut applied as ammonium nitrate. After removal of border rows, the three middle rows of 10 plants each (0.9 × 3.0 m) were harvested by mowing to leave a 10 cm stubble, weighed, and a subsample of approximately 600 g was taken and weighed fresh in the field. The subsamples were then separated into leaves and stems. Leaf sheaths were included with stems. Subsamples were forced-air dried at 60°C for 72 h, weighed, and ground in a Wiley Mill to pass through a 1 mm screen. Leaf and stem percentages were calculated.

Ground leaves and stems were analysed for crude protein (CP) concentration and *in vitro* organic matter digestibility (IVOMD) using a modified two-stage digestion procedure (Moore & Mott 1974). A modified aluminium block digestion procedure (Gallaher et al. 1975) and semi-automated colorimetry (Hambleton 1977) were used for analyses of N concentration. Whole-plant IVOMD and CP were calculated from the laboratory data for leaf and stem percentages in the dry matter harvested. Data were analysed as a split-plot in time design with Proc GLM of SAS (SAS Institute 1989).

RESULTS AND DISCUSSION

Population development

The mean number of inflorescences in the HEAD 1 population was lower than in the BASE population and the HEAD 2 population was intermediate (Table 1). It was speculated that the soils where the two selections were planted were less fertile than where the initial population was planted. The soil of the initial populations was an inceptisol, while that of the selections was a spodosol. The latter has a lower fertility and is seasonally waterlogged.

Heritability estimated for number of inflorescences ranged from 0.37 to 0.74. Heritability estimates increased with each successive cycle of selection for number of inflorescences, indicating that no decrease in variability occurred, due to the inter-mating technique used. The intercrossing of detached culms in close proximity under a large paper bag should have maximised gamete recombination with a control of both male and female progenitors. Other researchers using similar inter-mating techniques with other species have not seen a decrease in variability (Burton 1982).

The 50 half-sib families in BASE varied in leaf width from 0.8 to 1.3 cm and had a mean of 1.0 cm (Table 1). The selected families varied in width from 1 to 1.3 cm, and the selected plants had a mean of 1.3 cm. Heritability value for width of leaves was 0.59, and a gain of 18% from one cycle of selection was predicted (Table 1).

Population comparison

Wide-spacing experiment

In the wide-spacing experiment, broad variability was found for each morphological characteristic evaluated. The maximum culm and canopy heights were 2

and 1.3 m, respectively. Leaf width varied from 0.7 to 2.1 cm and inflorescence length from 11 to 35.3 cm. Four plants (1.3%) did not flower and the maximum number of inflorescences per plant was 120.

The correlation coefficient between vegetative and culm heights was 0.59 ($P < 0.01$), but R values were lower among the other variables. The correlation of number of inflorescences with inflorescence length was negative (-0.14 ; $P < 0.01$). These values agree with those of Hacker & Cuany (1997) who obtained a mean correlation of -0.17 for four cultivars of *setaria* in Australia.

Differences among populations were found for all morphological characteristics (Table 2). Selection for increased number of inflorescences decreased canopy and culm plant heights and inflorescence length in the second cycle, but had no effect on width of leaves. Despite a 17% increase over the BASE population in number of inflorescences with two cycles of selection, the increase was not significant. One possible reason for this is that the heritability estimates of 0.37 and 0.51 for BASE and HEAD 1, respectively (Table 1), were lower than those of Hacker & Cuany (1997) who obtained estimates of 0.63 to 0.80 for four cultivars.

The LEAF 1 population and 'Solander' had significantly wider leaves than all other populations (Table 2). Leaf width had a higher heritability than number of inflorescences (Table 1), thus it was expected that one cycle of selection would significantly increase leaf width. In Australia, Hacker & Bray (1981) found high heritability estimates for leaf width and a positive correlation with inflorescence number. In the present experiment, this correlation was low and negative (-0.14 ; $P < 0.01$). Selection for this trait increased the leaf width from 1.2 to 1.4 cm without changing the other morphological characteristics.

Table 2 Means of morphological characteristics recorded for four selected populations and one cultivar of *Setaria spachelata* in the wide-spacing experiment in September 1999. Means followed by the same letter within each column do not differ significantly at $P > 0.05$, according to the Waller-Duncan multiple comparison procedure.

| Population | Canopy height (cm) | Culm height | Leaf width | Inflorescence length | Inflorescence |
|------------|--------------------|-------------|------------|----------------------|---------------|
| BASE | 91a | 159a | 1.2b | 21.4a | 54a |
| HEAD 1 | 86ab | 154ab | 1.2b | 20.7a | 57ab |
| HEAD 2 | 82b | 144c | 1.1b | 17.5b | 63a |
| LEAF 1 | 88a | 155ab | 1.4a | 21.4a | 57ab |
| 'Solander' | 91a | 152b | 1.4a | 21.6a | 43c |

Inflorescence numbers per plant varied from 43 to 63 for the different populations, a narrower range than the 29 to 71 inflorescences per plant obtained by Hacker & Cuany (1997) for four cultivars. 'Solander' had 47 inflorescences per plant, similar to that (44) obtained in the present experiment (Table 2). The level of N application strongly influences number of inflorescences (Hacker & Jones 1971; Hacker 1994; Dwivedi et al. 1999) and the effect of N on seed yield and inflorescence number was linear (Hacker & Jones 1971). Growth condition, as plant spacing, also affects inflorescence numbers.

Selection for increased number of inflorescences or for leaf width had no effect on pure seed production (Table 3). The release of 'Solander' was mainly based on its consistently higher seed production when compared to 'Narok' (Hacker 1985, 1994). Seed yields of 'Solander' were 9 and 58 kg ha⁻¹ with the addition of 25 and 100 kg N ha⁻¹, respectively (Hacker 1985), although there are reports as high as 100 kg ha⁻¹ (Hacker 1991b). In the present experiment, 'Solander' was the lowest yielding entity (Table 3).

Seed weight per inflorescence was higher than reported by Hacker & Jones (1971). For two introductions, they obtained seed weight of 45 to 65 mg inflorescence⁻¹, while in the present experiment the variation was from 95 to 155 mg inflorescence⁻¹ (Table 3). Considering the number of inflorescences produced by each plant, the estimated seed production plant⁻¹ varied from 4 ('Solander) to 8.6 g plant⁻¹ (LEAF 1) or from 40 to 86 kg ha⁻¹ estimated at 1 plant m⁻² (Table 3). In Australia, 11 populations varied from 51 to 293 kg seed ha⁻¹ (Hacker 1991b) and two introductions varied from 6 to 39 kg seed ha⁻¹ (Hacker & Jones 1971). In India, one cultivar yielded 70 kg seed ha⁻¹ (Singh et al. 1995).

Close-spacing experiment

In the close-spacing experiment, significant differences among populations, harvests and interaction between harvest and population were found for stem and total dry matter yields, leaf percentage and leaf:stem ratio. Differences among populations were found for leaf dry matter yield. Yield data are presented as harvest totals, and leaf percentage and leaf:stem ratio are presented as mean of harvests for ease of discussion of the entire experimental period, because data of individual harvests have no agronomic significance. Selection for inflorescence number decreased total dry matter yield due to a reduction in the stem production (Table 4). Consequently, this selection increased the percentage of leaves and leaf:stem ratio due to a reduction of the stem proportion of plants.

LEAF 1 was similar to 'Solander' in all agronomic characteristics evaluated (Table 4). Thus, our one cycle of selection for increased leaf width moved the BASE population to a phenotype similar to 'Solander'. 'Splenda' was not different from BASE, our selected populations, and 'Solander' in total yield, but had more stems and a smaller leaf percentage than HEAD 2, LEAF 1, and 'Solander'. 'Thompson Falls' and 'Fenwicks' had the lowest yields. 'Fenwicks' had the lowest leaf dry matter yield and leaf percentage, and 'Thompson Falls' had the lowest stem and total dry matter yields (Table 4).

Total dry matter yields obtained for the two harvests for the eight populations varied from 2730 to 6550 kg ha⁻¹ (Table 4). Levels of production are comparable to those obtained in Australia under grazing, where 3510 to 4790 kg ha⁻¹ (Jones & Evans 1989) and 3400 to 5280 kg ha⁻¹ (Hacker & Evans 1992) were obtained for three and four cultivars of

Table 3 Seed yield in four selected populations and one cultivar of *Setaria sphacelata* in 1999 in the wide-spacing experiment. Means followed by the same letter within each column do not differ significantly at $P > 0.05$, according to the Waller-Duncan multiple comparison procedure.

| Population | Pure seed yield | | |
|------------|-----------------------------------|---------------------------|-------------------------|
| | (mg inflorescence ⁻¹) | (g plant ⁻¹)* | (kg ha ⁻¹)* |
| BASE | 141ab | 7.3a | 73a |
| HEAD 1 | 122ab | 6.9a | 69a |
| HEAD 2 | 103b | 6.5ab | 65ab |
| LEAF 1 | 155a | 8.6a | 86a |
| 'Solander' | 95b | 4.0b | 40b |

*Estimate based on number of inflorescences and production per inflorescence.

setaria, respectively. Leaf production varied from 690 to 3180 kg ha⁻¹ (Table 4), a wider range than the range of 1340 to 1760 kg ha⁻¹ obtained in Australia (Hacker & Evans 1992).

HEAD 1, 'Splenda' and 'Fenwicks' had leaf:stem ratios less than 1.0. 'Fenwicks' had a particularly low leaf:stem ratio of 0.25, equivalent to only 20% leaf. In Kenya, setaria leaf percentage decreased from 60 to 40 to 24% with regrowth periods of 3, 6, and 9 weeks, respectively, and in another experiment, from 62 to 32% with regrowth of 2 and 6 weeks, respectively (Wijk 1980). However, higher leaf:stem ratios than the ones reported here were observed in a grazing trial in subtropical coastal lowlands of south-east Queensland. Four cultivars of setaria varied from 0.94 to 2.08 leaf:stem ratio, with a mean

of 1.56 under rotational stocking (Hacker & Evans 1992).

There were no differences among populations for mean CP concentration in leaves and stems, but whole-plant CP differed significantly among populations. Data for CP are given as a mean of harvests, despite interaction with harvests, for the same reasons mentioned above (Table 5). Selection for increased leaf width resulted in an increased whole-plant CP concentration for LEAF 1 to a level similar to 'Solander' (Table 5). This increase can be related to a decrease in stem production obtained with selection.

Leaf CP varied from 129 to 182 g kg⁻¹, while stem CP varied from 72 to 123 g kg⁻¹. In the whole plant, CP values varied from 108 to 138 g kg⁻¹ (Table 5).

Table 4 Total leaf, stem, and total dry matter yield, mean leaf percentage, and leaf/stem (L/S) ratio of four selected populations, two cultivars, and two ecotypes of *Setaria sphacelata* grown in the close-spacing experiment in 2000. Means followed by the same letter within a column do not differ significantly at $P > 0.05$, according to the Waller-Duncan multiple comparison procedure.

| | Dry matter yield (kg ha ⁻¹) | | | Leaf percentage | Leaf:stem ratio |
|------------------|---|---------|---------|-----------------|-----------------|
| | Leaf | Stem | Total | | |
| BASE | 3180a | 3370ab | 6550a | 53b | 1.3b |
| HEAD 1 | 2240bc | 2840abc | 5080abc | 44c | 0.8c |
| HEAD 2 | 2880ab | 1970cd | 4840bc | 59a | 1.5ab |
| LEAF 1 | 3150a | 1860cd | 5010abc | 63a | 1.7a |
| 'Solander' | 3110a | 2350bc | 5460ab | 58ab | 1.4ab |
| 'Splenda' | 2490ab | 3670a | 6160ab | 41c | 0.7c |
| 'Fenwicks' | 690d | 2710abc | 3400cd | 20d | 0.3d |
| 'Thompson Falls' | 1540c | 1190d | 2730d | 58ab | 1.4ab |

Table 5 Mean crude protein and *in vitro* organic matter digestibility (IVOMD) in the leaves, stems and whole plant of four selected populations, two cultivars and two ecotypes of *Setaria sphacelata* grown in the close-spacing experiment in 2000. Means followed by the same letter within a column do not differ significantly at $P > 0.05$, according to the Waller-Duncan multiple comparison procedure.

| | Crude protein | <i>In vitro</i> organic matter digestion | | |
|-----------------------|---------------|--|-------|-------------|
| | Whole plant | Leaf | Stem | Whole plant |
| (g kg ⁻¹) | | | | |
| BASE | 112bc | 481b | 524bc | 495bc |
| HEAD 1 | 127ab | 487b | 528bc | 510bc |
| HEAD 2 | 129ab | 495b | 527bc | 507bc |
| LEAF 1 | 138a | 469b | 524bc | 489bc |
| 'Solander' | 133a | 471b | 506c | 486c |
| 'Splenda' | 123abc | 483b | 550ab | 521ab |
| 'Fenwicks' | 108c | 573a | 579a | 579a |
| 'Thompson Falls' | 135a | 519b | 504c | 512bc |

These CP values were high in comparison to other tropical forage grasses which frequently have less than 70 g kg^{-1} . They were also much higher than the 75 to 88 g kg^{-1} values reported by Jones & Evans (1989) for three cultivars of setaria under grazing fertilised with $170 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ in three split applications in early spring, early summer, and early autumn. However, CP values of 146 g kg^{-1} were reported in Brazil when fertilised with $100 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ in two split applications (Almeida & Flaesso 1991). Protein decreases rapidly with plant maturity, and other studies have reported values above 95 g kg^{-1} and frequently above 125 g kg^{-1} in Australia (Bray & Hacker 1981).

Differences among populations and harvests occurred for leaf, stem and whole-plant IVOMD. Interaction between population and harvest occurred only for stem IVOMD. Data for IVOMD are presented as a mean of harvests for the same reasons mentioned above. Selection for number of inflorescences and selection for increased width of leaves did not affect IVOMD (Table 5). Leaf IVOMD varied from 469 to 573 g kg^{-1} . 'Fenwicks' was significantly higher in leaf IVOMD than all other populations. With the exception of 'Thompson Falls', stem digestibilities were higher than leaf digestibilities. This was not expected, because Hacker (1974) found digestibilities in leaves to be 20 to 30 g kg^{-1} higher than in stems. However, it agrees with Hacker (1971) in that the low quality of setaria in comparison to temperate grasses results from low leaf digestibility and not low stem digestibility.

The digestibilities obtained in the present experiment are at the lower end of values reported for tropical grasses. The regrowth period of 6 weeks between harvests permitted the plants to mature and to flower. Flowering was very intense, especially in the second harvest, and digestibilities were lower than in the first harvest. Flowering affects digestibility, and in Australia, values for 'Kazungula' dropped from 660 g kg^{-1} before flowering to 400 g kg^{-1} after intense flowering (Moss & Murray 1992).

CONCLUSION

Selection for leaf width increased the width of leaves, the percentage of leaves, leaf:stem ratio, and CP concentration in the whole plant, but it decreased stem dry matter yield and did not affect leaf dry matter yield and IVOMD. Selection for increased number of inflorescences decreased canopy and culm heights, inflorescence length and stem and total dry

matter yields, probably because of a partitioning to increase number of inflorescences. However, Hacker & Bray (1981) stated that selection for increased number of inflorescences was an indirect method for increasing dry matter yield, due to an increase in the weight of the stems. These data suggest that there was a compensating effect such that increasing inflorescence number resulted in a decrease in stem length.

Despite heritability for inflorescence number being 0.4 , this character did not respond well to selection, the realised heritability being lower, with evidence that only a 17% gain in number of inflorescences was achieved. A possible explanation for the lack of response is that the experimental protocol may not have allowed the separation of the genetic variance component from the environmental variance component of the total phenotypic variance, or due to adaptive limitations for this character inherent to the species.

In general, the selection processes moved the populations to less stemmy populations, by decreasing the stem component while maintaining the leaf component of the plants, thus increasing whole plant crude protein concentration. This was possible due to the high negative correlation of stem yield with leaf percentage and whole plant crude protein in the initial BASE population, and its positive correlation with total dry matter yield. Thus, a decrease in stem yield, as observed in the selected populations, was accompanied by an increase in leaf percentage and whole plant crude protein concentration. Leaf yield or IVOMD, on the other hand, were not correlated with any of the agronomic characteristics evaluated.

The recurrent half-sib family selection methodology with detached culms technique for inter-mating selected plants proved to be an adequate methodology for developing improved populations in setaria. It brought about rapid modification of morphological and agronomic traits with minimal labour and costs, and the advantages of controlling both female and male progenitors.

Released *S. sphacelata* cultivars have not been formerly evaluated under Florida conditions, due to lack of available commercial seeds. However, since the latitudes of Florida ($29^{\circ}40'N$) and Australia ($27^{\circ}30'S$) where the breeding work was done and the cultivars used are comparable, and the species is recommended for Australia and for humid soils, characteristic of many soils in Florida, it thus appears to be a promising plant for Florida conditions. The main practical finding from these experiments is

that the species proved to be promising for Florida. The germplasm was plastic enough that selection and breeding for morphological and agronomic traits were successful, particularly for improvement of leaf width. Dry matter production levels were comparable to other tropical pasture grasses and CP concentration levels were higher. Levels of IVOMD, however, were lower than reported for setaria grown in other locations and lower than for some other tropical grasses of similar age.

The use of setaria in Florida depends on incorporating tolerance to winter cold and to chinch bug *Blissus leucopterus* (Homoptera: Lygaeidae) into high yielding, high quality populations developed. Tolerance to winter cold was achieved in Jank et al. (2002), due to the incorporation of genes of the local persistent population found at Ona, Florida. Chinch bug was found to be a problem during the development of these experiments, since a trial under grazing at Ona, did not survive due to attack by this insect. Levels of chinch bug have been seen to rise during certain years in Florida, and outbreaks usually occur in spring and early summer, especially when dry edaphic conditions exist. In summer, heavy and frequent rains help control the chinch bugs by killing the young insects and the eggs. In addition, rainfall also favours the development and spreading of the fungi that kill the chinch bugs (Kuiter & Nutter 1952). Before this grass may be recommended as an improved forage in Florida, populations tolerant to chinch bug must be developed and persistence under grazing needs to be assessed.

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