

## REVIEW

## THE SETARIA SPHACELATA COMPLEX — A REVIEW

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## INTRODUCTION

The genus *Setaria* includes approximately 125 species of temperate, sub-tropical and tropical distribution (148), and is of considerable agricultural importance. *S. italica* is a grain crop grown widely in temperate regions. A number of species for example *S. viridis* are noxious weeds of arable land (148). Of particular interest to pastoralists is the closely related group of species which has come to be known as the *S. sphacelata* complex, and members of this group are being grown increasingly in the higher rainfall areas of sub-tropical and tropical Australia, and throughout the tropics and sub-tropics. Since the release of the cultivar Nandi in 1961 (22) and more recently Kazungula in 1962 (22), large areas have been planted to setaria in Queensland and northern New South Wales and effort is being put into defining management practices for maximum production, studying nutrient requirements, introducing new genotypes and breeding for improvement of yield and quality. A considerable amount of information is now available and it is of value at this stage to assemble the information so far obtained. Much of the information is observational and has not been tested critically. An attempt is made to indicate where further information is required to substantiate certain claims so that a more objective assessment of the value of this complex can be made.

## NOMENCLATURE

The taxonomy of the *Setaria sphacelata* complex is still in some doubt, and further investigation is necessary for a useful classification of this complex. In East Africa four species are included, these being *Setaria sphacelata sensu stricto* (Schumach) Stapf et C. E. Hubbard ex M. B. Moss, *S. anceps* Stapf, *S. trinervia* Stapf and *S. splendida* Stapf (34). In other regions of Africa there are species of *Setaria* which closely resemble *S. sphacelata*, for example *S. neglecta* de Wit and *S. flabellata* Stapf in South Africa (58) and it is possible that the limits of the complex should be extended to include these

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species. The West African *S. aurea* Hochst ex A. Br. is probably con-specific with the East African *S. trinervia* (59). In South Africa *S. sphacelata sensu stricto* has been separated into a number of species, sub-species and varieties, but Chippendall (58) considers that this classification is not particularly useful and that *S. sphacelata* should be treated simply as a polymorphous species comprising a number of forms.

At present, then, the species *S. sphacelata*, *S. anceps*, *S. trinervia* and *S. splendida* should be considered as distinct (34, 59, 155) with the two cultivars "Nandi" and "Kazungula", belonging to *S. anceps*.

### BOTANICAL CHARACTERISTICS

Descriptions of the four species in the *S. sphacelata* complex are available from a number of sources (22, 33, 34, 58, 59, 155). They are tufted perennials, more or less rhizomatous or without rhizomes, and very variable both within and between species with respect to vegetative characteristics. The inflorescence is a more or less cylindrical spike-like panicle up to 18 in. or more long in some strains. Spikelets are subtended by 6-15 bristles up to  $\frac{1}{2}$  in. long, and are elliptic-oblong in shape with two florets, only the upper being fertile. The lower glume is about half the length of the spikelet, the upper rather longer.

The main characters distinguishing *S. anceps*, *S. trinervia* and *S. sphacelata* are vegetative (32, 58, 59, 155). *S. anceps* is tall, tufted, without fibre at the base and without elongated rhizomes. Young shoots are fan-shaped and strongly compressed at the base. Sheaths of basal leaves are broad, sharply keeled; leaves are generally broad. *S. trinervia* is shorter, with abundant fibre (split sheaths) at the base of mature plants. Young shoots are not fan-shaped and not compressed. Sheaths are only slightly keeled, leaves are narrow. *S. sphacelata* is medium to large, sometimes rhizomatous, and without fibre at the base. Young shoots are not flabellate and not compressed. *S. splendida* is similar to *S. anceps* but considerably larger—it is taller, the leaves are longer and wider, the internodes are thicker and there are more internodes per culm. However, it is still uncertain whether these two species may reliably be separated (Clayton, pers. comm.).

Inflorescence characters may be helpful in identification, but are not conclusive (Napper, pers. comm.), *S. trinervia* usually, but not invariably, has a three-nerved upper glume while the other species have upper glumes with five nerves. Differences in spikelet length have also been used as key characters (155).

### NATURAL DISTRIBUTION

The *Setaria sphacelata* complex is confined to the continent of Africa. Although widespread within Africa it is rarely dominant over large areas. *Setaria incrassata* is dominant over large tracts of heavy black soil country in W. Angola, N.E. Uganda and Ethiopia but *Setaria sphacelata* dominant grassland is confined to areas of Ethiopia and is regarded as a transitional type of grassland (136). Although rarely dominant over large areas it occurs frequently in grasslands dominated by *Andropogon*, *Hyparrhenia* and *Themeda* species on a range of soils from waterlogged, or even swampy conditions, on clay soils in parts of Uganda (136) to poor sandy and granitic soils in W. Africa (136). *Setaria trinervia* is often associated with wetter conditions or seasonably waterlogged conditions and in Uganda is frequently found on the edges of swamps in tussocks associated with swampworm activity (167). In Central Africa *Setaria sphacelata* occurs in Headwater Valley, Riverine and Flood-plain grasslands, and also in secondary upland grassland (166).

In a survey in S.W. Uganda over an area of 3,000 sq. miles, with an altitudinal range of 3,000-5,000 ft. and covering 15 ecological zones *Setaria sphacelata* was one of the three most commonly occurring grasses. In only two of the 15 ecological zones was it not found. Under the dense cattle and game grazing of the area it was more frequent than *Chloris gayana*, *Panicum* sp. or *Cynodon dactylon* (161). In northern and

eastern Nigeria at altitudes around 5,000 ft. *S. anceps* is co-dominant with *Hyparrhenia diplandra* and *Andropogon auriculatus* and is said to provide some of the best natural grazings for beef cattle in the area (93, 163).

The altitudinal range for the complex is also wide. In E. and Central Africa it occurs from sea level in coastal forest glades to moorlands and forest edges at up to 10,000 ft. (71, 154), though more commonly in the 2,000-8,000 ft. range. The complex appears to be adapted to wetter condition with most associations occurring above a rainfall of 30 inches with no prolonged dry season (136).

In East Africa *Setaria anceps* is frequently found in low lying areas with a high water table, on stream banks and forest edges. It does not appear to be common on alkaline soils or on very acid soils—the majority of collections being made at a soil pH of 5.5-6.5 (98).

### GEOGRAPHICAL RANGE AS A FODDER AND PASTURE SPECIES

Despite the considerable variability within the *Setaria sphacelata* complex only five varieties have been used on a practical scale.

Kazungula, Bua River and *Setaria splendida* have been used and developed mainly as fodder grasses for use as silage, hay or green chop. Nandi setaria, however, was selected by D. C. Edwards mainly as a pasture grass for use in leys and du Toitskraal setaria has been used for dry-land pastures in lower rainfall country than the other cultivated setarias.

The origin of the cultivated forms of *S. splendida* is not known with certainty—they occur in E., Central and S. Africa on swamp margins and were collected in these localities for experimental work as early as 1938 by Pole Evans (3, 132).

The other setarias have been given the names of their original collection sites—Kazungula in Bechuanaland\* (112), Bua River in Nyasaland, du Toitskraal in Rhodesia (162) and the Nandi district in W. Kenya (35).

There are no reports of du Toitskraal setaria as a commercial sown pasture plant outside South Africa. There it has been recommended for areas with 20-30 inches of summer rainfall in the north-eastern Cape Province as a drought resistant pasture grass which retains some greenness and palatability into winter (162).

The remaining setarias are recommended for areas having a rainfall above 30 inches/annum (22, 43, 96, 112) with the proviso that under fertile conditions Kazungula setaria may be grown under 23 inches of rainfall/annum. It seems unlikely that in Australia these introduced species can be grown successfully below this limit. Although there is little critical data it is apparent that most sowings have occurred in Queensland in areas with mean annual rainfall above 30 inches—(Personal communication—Queensland Department of Primary Industries). In areas of lower rainfall published results have shown setaria to be inferior to Rhodes grass, Green Panic or buffel grass (72, 115). In Tanzania at Mpwapwa *Chloris gayana*, *Cenchrus ciliaris*, *Cynodon plectostachyum* and *Pennisetum purpureum* survived in swards under drought conditions whereas *Setaria sphacelata* died out except where the land had previously been cropped for one year (and presumably more moisture stored) (10).

In addition to the limit set by rainfall, low temperatures also define the areas where they may be grown. In Canberra Nandi grows in summer but is killed out in winter (153), and in southern New South Wales Kazungula fails to persist (64). In Lesotho (Basutoland) at about 5,000 ft. altitude frost and summer drought result in complete kill of many subtropical species including *S. sphacelata*. *Panicum coloratum* (makarikari), *Eragrostis curvula* and *Digitaria smutsii* survived these conditions (4). On the Darling Downs in Queensland both Nandi and Kazungula suffered heavy losses of established plants over winter (107). In low lying areas at lower altitudes in Queensland considerable death of plants in addition to the killing of the above ground portions of the plants can occur. From observations at Samford a higher proportion of

\* From *The Times World Atlas* it appears that Kazungula is actually in Zambia.

Nandi plants die at temperatures below 25°F than do *S. splendida* plants and a range of Kazungula and Bua River introductions, and is often replaced by *Paspalum dilatatum* in the frost affected plots (R. J. Jones unpublished data).

Waterlogging may be a problem in some coastal areas, and both Nandi and Kazungula show tolerance to flooding (22, 96). Kazungula is particularly flood tolerant (61).

Since the first reported uses of Kazungula and Bua River in S. Africa in 1937 and the selection by D. C. Edwards of Nandi in Kenya in 1947 these grasses have been used in a number of tropical and subtropical countries. Promising results with these varieties have been achieved in Kenya (16, 20, 21, 79), Uganda (95), Tanzania (10), Mauritius (25), Ghana (108), Malagasy (Madagascar) (31, 70, 137), Malawi (14), S. Africa (43, 150), Mozambique (65), Congo (5, 7, 8, 15, 17, 18, 62, 120), Ivory Coast (53), Sierra Leone (6), Rhodesia (9, 12, 14), Florida (117), Trinidad (80) Brazil (177), Queensland (1, 13), New South Wales (63, 175), New Guinea (23), Philippines (73), Taiwan (114). In some areas with a mediterranean climate setaria has been used successfully as an irrigated summer grass, e.g. Morocco (74, 75) and Israel (Z. Naveh, personal comm.). In Israel it is reported to be higher yielding than Rhodes grass under the same conditions (Z. Naveh personal comm.).

In addition to its use as a pasture grass, setaria has been found to increase soil organic matter (26, 116). In this respect it was superior to other grasses tested in Uganda (116).

#### ESTABLISHMENT

*Setaria* may be established vegetatively from rooted tillers or by sowing seed. *S. splendida* produces little viable seed but is readily propagated from tillers. Care is necessary to ensure that the planting material is not buried as unlike some other vegetatively propagated grasses (e.g. sugar cane) setaria fails to establish unless part of the tiller remains above ground (43). Optimal spacing of the planting material may vary greatly depending on the rainfall conditions and the proposed utilization of the pasture. If required for dry season standover fodder planting distances would be wider than those required for a grazed pasture. In Taiwan 50 cm × 25 cm is recommended for Kazungula (114), whereas in S. Africa spacings of 3-3½ ft. between rows and 12-18 inches between plants are used (43). Spacing of *S. splendida* is optimal at 70 × 90 cm in Mozambique (65).

If established from seed, good seed bed preparation designed to maximise soil moisture retention and to destroy weeds is advocated (112). And tendency for the soil to crust will prevent seedling emergence and result in poor stands. Recommended sowing depths are ¾ inch for Kazungula (112) and 0-1 inch for Nandi depending on soil type and moisture conditions (36), with the seed bed rolled after sowing. If planted deeper than this the seedlings may fail to emerge. Care should be taken not to graze too early as young plants are readily uprooted by the grazing animal.

In Kenya successful establishment of setaria can be achieved by undersowing to maize, wheat or fodder crops to be taken for silage or grazing, but the rainfall and soil fertility need to be good (134). The practice is not recommended, however, if clover is included in the mixture since competition for light is too severe for good establishment (134).

Seed quality in the various countries varies greatly so that recommended seeding rates vary from 15 lb/acre (113) to ½ lb/acre (96). The recommendation from Kenya (16) of ½ lb pure live seed (P.L.S.)/acre is a better guide. With the commercial seed available in Australia 1 to 2 lb/acre of commercial seed may be regarded as suitable.

Improved establishment following seed dressing with dieldrin at 10 gms active ingredient/kg seed is reported from Mauritius where ants can be troublesome (24).

On most soils in S. Africa dressings of phosphate at planting result in more rapid establishment (42, 112) and the correction of other known nutrient deficiencies must

also lead to more rapid establishment. Under weedy conditions establishment is often slow. At the C.S.I.R.O. Pasture Research Station, Samford, many sowings have appeared to be failures in the first year due to heavy weed infestation but have developed into excellent stands in the second year.

### PASTURE MIXTURES

In the Congo setaria is grown in mixtures with other grasses and is said to give good results with *Chloris gayana*, *Digitaria umfolozi* and *Melinis minutiflora* (5, 7). In Kenya Nandi setaria is reported as suppressing associated *Chloris gayana* (11). This aggressiveness when sown in mixtures with other species, especially after the first year, was revealed in the results of a 4 year study in S.E. Queensland where setaria was combined with 3 Rhodes grasses, 3 Paspalum species and Pangolagrass in two or three species mixtures. After the first year Nandi setaria dominated the mixtures and suppressed all species except Pangola (104). Under irrigation on an alluvial soil Nandi setaria also suppressed three *Paspalum* species sown with it. The results of both these experiments showed that there was no advantage in using mixtures of summer growing species (104, 105).

There are few reports comparing the ability of setaria or other grasses to combine with legumes. In S. Africa and Rhodesia *Glycine javanica* is said to give good results as an associate legume (9, 112, 164) and in East Africa good associations with *Trifolium semipilosum* (156), *T. reupellianum*, *Desmodium uncinatum* and *D. intortum* have been obtained in experimental pastures (127, 157), whereas in Queensland and northern New South Wales Nandi setaria has been reported as forming stable mixtures with glycine, siratro, greenleaf and silverleaf desmodium and is recommended for mixtures with these species (69, 130). The period of stability and the conditions under which stability occurred were not defined. Nandi is said to be less aggressive than Kazungula in association with legumes, having a lower summer peak of production and lower height at flowering (22, 96). At Samford, S.E. Queensland, *S. splendida* appears to be more aggressive than other introductions tested, and on fertile soil eliminated Siratro sown with it (99, 100).

In a comparison with Samford Rhodes grass over five years Nandi setaria enabled higher legume and nitrogen yields to be achieved in the first two years, thereafter there was little difference between these grasses. The slower establishment of the setaria appeared to favour the associated legumes—Siratro and Phasey bean (99). Excellent results have been achieved on alluvial soils using a number of setaria introductions in association with ladino white clover in S.E. Queensland. Yields of up to 19,000 lb. D.M./acre without nitrogen fertilizer or irrigation were achieved (99). On a similar soil under irrigation Nandi setaria in combination with winter grasses and white clover yielded over 20,000 lb. D.M./acre/yr on a system of 5 weeks rest followed by 1 week of grazing (105), the white clover contributing more to pasture yields in mixtures with setaria than in mixtures with Samford Rhodes grass.

The stability of the grass/legume association depends on the legume chosen, the grazing management (156) and also on the fertilizer dressings used—especially nitrogen. In setaria/legume mixtures dressed with nitrogen the legume rapidly decreases or dies out even when the nitrogen is applied outside the growing season of the legume (103).

### PRODUCTION AND MANAGEMENT

Within the zones to which setaria is adapted yields can vary greatly depending on the rainfall and fertility conditions encountered. As a result comparative production figures are more important than the actual yields. Most of the production estimates in the literature have been obtained under cutting and comparisons of setaria with other tropical species made. Elephant grass—*Pennisetum purpureum* has outyielded setaria

in Tanzania (141), Brazil (177), Rhodesia (12), Kenya (79), the Congo (8), and Queensland (81). However, the spacing of the plants appear to influence the comparison since in Malawi (Nyasaland) Kazungula setaria outyielded elephant grass at 3 ft. spacing but not at 6 or 9 ft. spacing (12).

In Tanzania mean yields of 108, 97 and 63 tons green material in acre were obtained over a four-year period from elephant grass, *Setaria splendida* and *S. sphacelata* (141). The higher yielding ability of *S. splendida* compared with *S. sphacelata* has been obtained in other areas under cutting (51, 143, 144, 145, 147) but under grazing the Kazungula and Bua River setarias are capable of giving equivalent yields (99, 100).

Yields of Kazungula and Bua River setaria were similar in Mauritius (25) although under good conditions Bua River when cut at the pre-flowering stage outyielded Kazungula by 10-20% at each cutting (25). Under dry conditions, however, Kazungula gave one more cut/annum. Results in Australia indicate that Kazungula is potentially higher yielding than Nandi (99, 106). This is not to say that Nandi is low yielding, for in a study of yields under grazing Nandi outyielded 10 other grasses compared with it including Rhodes, *Paspalum* species, Pangola, and *Pyparrhenia hirta* (104).

Although outyielded in most trials by Elephant grass the setarias have gained popularity in some areas due to their ease of handling compared with Elephant grass, ease of establishment, better compatibility with legumes and hence ease of management under grazing (12).

#### Fertilizer Responses

Marked responses to nitrogen fertilizer have been recorded for setaria. In Kenya and Rhodesia the application of sulphate of ammonia to natural pasture increased the proportion of setaria and also increased yield (133; 169). In Rhodesia Kazungula setaria outyielded Sabi panicum, Star grass, Katambora Rhodes, Bambatsi Panicum and Ermelo love grass at 60 and 120 lb. N/acre. Linear responses in terms of dry matter and protein were recorded of 30 lb. dry matter and 3 lb. protein per lb. of nitrogen applied (169). In another experiment Kazungula gave higher yields than Sabi panicum, Katambora Rhodes and giant Rhodes and in the one season produced 55 lb. dry matter per lb. of N applied at the 120 lb. N/acre rate (169).

In Queensland high responses to nitrogen applied as urea have also been obtained even in dry seasons. Over a 4 year period mean responses of 40-30 lb. D.M./acre were achieved with applications of 100 and 300 lb. N/acre/annum (101).

Response of setaria to different forms of nitrogen fertilizer has not apparently been studied, and only one experiment was noted in which the effect of mode of application of the nitrogen was investigated. In this experiment with Kazungula (169) significantly lower yields of dry matter were obtained when 400 lbs. sulphate of ammonia were applied in eight equal dressings over the season then when given in one, two or four applications. It also appears that early application increases dry matter yield but has little effect on nitrogen percentage; with late application nitrogen content increases without increasing dry matter yield (14).

Little information is available on responses to other nutrients in the field. In S. Africa phosphorus is recommended for rapid establishment and high production (112), but no responses were reported for potassium. In an N.P.K. factorial trial over a four-year period in Queensland responses to both P and K were evident, particularly at high levels of N. In spite of a basal application of 6 cwt. superphosphate/acre responses to P increased with time whereas responses to K decreased with time (101). On these phosphorus deficient phyllite soils an annual application of 2-3 cwt. superphosphate and 1½ cwt. KCl was advocated for high production (101).

Pot experiments with contrasting soils showed that the critical level of K in Nandi was about 1.0% of the dry matter. Above this value there was no yield response to applied K. However, in soils with ample K and on those fertilized with K, concentrations of 4% are common, and up to 7% have been recorded. This high content is usually associated with high yield, so the rate of K uptake by this plant can be particularly high. (I. F. Fergus and A. E. Martin personal comm.)

These workers also showed a marked ability of Nandi to utilize sources of potassium in certain soils containing illite or feldspars which were not available to Rhodes grass, so that the total amount of soil K removed by setaria before the exhaustion stage was reached was greater than that removed by Rhodes grass (I. F. Fergus and A. E. Martin personal comm.).

The maintenance requirements for pastures of setaria under grazing has not been determined. With pastures of Nandi at Samford applications of 2 cwt. superphosphate and 1 cwt. of KCl have maintained adequate levels in the herbage (R. J. Jones unpublished data).

South African work (49) has shown that Mn and probably B are definitely required by setaria (Kazungula) and requirements for Cu and Zn are probably quite low. Deficiency symptoms were developed for B and Mn and toxicity symptoms for B, Mn, Cu, and Zn. At sub-toxic levels, B had no effect on content of Cu, Fe, Mn, and Mo (118). Boron, calcium and sucrose are also necessary for pollen germination, and Cu, Mn, and Zn stimulate pollen germination in the presence of B (47, 48).

In the field setaria (particularly Nandi) exhibits colour symptoms suggesting mineral deficiency although the colour symptoms depend on the variety. Reddening of the leaves is commonly seen, especially under moisture stress. These symptoms are associated with deficiencies of N, P and S or a combination of these (2). Under drought conditions death of the leaf tips with characteristic corkscrewing of the dead tips indicates K deficiency. These conditions often disappear following rain.

Under certain conditions marked interveinal chlorosis indicative of Fe deficiency occur. Such symptoms are often transitory, only occurring in the very young growth. Extreme symptoms of this apparent Fe deficiency were also seen by one of us (R.J.J.) on setaria introductions tested on a highly calcareous soil in Upper Galilee in Israel. The symptoms were present even on older leaves and were more marked in plots fertilized with nitrogen.

#### *Management*

Most recommendations in the literature refer to cutting rather than grazing management. The aim has been to compromise between high yield with long cutting intervals and high quality with shorter cutting intervals. In Mauritius (25) cutting intervals of approximately 7 weeks are recommended and a similar interval is advocated in Tanzania under irrigation (141). Reports from Mozambique indicate that monthly cutting is optimal for *S. splendida* (65).

Extrapolation of the results of cutting trials has led to recommendations for grazing management. In E. Africa careful management to utilize the pasture when young and succulent is recommended (140), and in S. Africa light grazing for short periods, followed by resting is advocated (112). Such forms of utilization imply that other sources of feed are available in the non-grazing season. This is the exception rather than the rule in tropical countries where continuous grazing or very lax paddock grazing is practiced. Under continuous grazing Nandi has performed well on hill slopes in S.E. Queensland (100, 103).

Little experimental evidence is available to define the optimum grazing management for setaria pastures in any particular climatic zone.

#### *Fodder Conservation*

The potential of setaria for conservation purposes was recognized early in its development as a sown species (139). In S. Africa the Kazungula and related collections produced excellent silage readily consumed by cattle (42, 112), and in Rhodesia as a silage crop Kazungula outyields maize (109). Molasses at 4 gallons per ton of fresh material was advocated in S. Africa for excellent quality silage (112). Work in Queensland has shown that molasses is necessary for producing silage with a high lactic acid content (55), but well preserved silage can also be made in the absence of molasses although the lactic acid content is then low (54). The lactic acid content was not related

to the level of nitrogen fertilizer (25 or 100 lb N/acre/cut) or to the time of year the setaria was cut (56). Preservation of the silage appeared to be due to the high acetic acid content.

The palatability of *Setaria splendida* silage in the Congo was reported to be higher than that of Elephant grass silage although in the fresh state the palatability preferences were reversed (18).

*Setaria* has also been used for hay in S. Africa but difficulty is encountered in drying the stems of the Kazungula types. Cutting for hay at the pre head emergence stage is therefore recommended (112). Hay has also been made from natural grassland in Ghana in which *Setaria sphacelata* was a dominant species. Although the hay provided adequate energy, it was low in protein (111).

In Queensland preliminary studies with Nandi indicate that with favourable conditions (no rain) losses of less than 10% of the original dry matter and nitrogen present can be expected during curing. Storage losses of small lots of hay appeared to be low if the hay was well cured (57).

*Setaria* has also been recommended as a standover dry season feed in Kenya (21) and Uganda (95). However losses in dry matter and crude protein may amount to 33%.

### CHEMICAL COMPOSITION AND FEEDING VALUE

On the basis of chemical composition opinions differ as to the nutritive value of setaria. In Uganda in a comparison of a number of grasses in advanced stages of growth setaria was noted as one of the lowest in nutritive value (44, 45). Other workers in E. Africa (66), W. Africa (131) and S. Africa (176) have rated setaria as a good species but state that its nutritive value declines rapidly after flowering. Differences in yield, stage of growth fertility level and the particular strain used could account for the difference reported in the literature. Data on crude protein, crude fibre and other chemical constituents have been published by a number of authors in relation to ageing effects and differences between species (46, 66, 80, 109, 121, 122, 141, 142, 151). Dougall (66) using Nandi at Kitale, Kenya, showed a progressive fall in crude protein (15%-5%), digestible crude protein (10%-2%), total digestible nutrients (62%-49%), and gross digestible energy (66%-50%), while nutrient ratio (5.0 to 26.3) and crude fibre (23%-42%) increased with age over a four-month period.

Milford and Haydock (121) also showed with Nandi a rapid decline in crude protein for 40-60 days, followed by a levelling off. The pattern was similar to that for Rhodes grass, Kikuyu grass, Pangola grass, Buffel grass and *Sorghum almum*. The levels of crude protein were however higher than for Pangola, similar to Rhodes grass, but lower than for Kikuyu, Buffel grass and *Sorghum almum*. Since the soils on which they were grown differed in inherent fertility these differences cannot be ascribed solely to species differences. Crude protein digestibility was significantly related to percent crude protein content from which it could be predicted.

A somewhat unusual feature of setaria (Nandi) is the presence of free ammonia. Compared with *Brachiaria ruziziensis* Nandi built up appreciable quantities of ammonia with increasing nitrogen application (28, 29). Unlike *B. ruziziensis*, the levels of nitrate in Nandi were quite low with nitrogen fertilization although ammonium nitrogen levels were high, declining with age (68). Differences between free amino acid contents of the two grasses were insufficient to explain the greater accumulation of ammonium N during early growth of Nandi (91, 92). Large differences in acidity between Nandi and *B. ruziziensis* (and many other grasses) appears to be due to a high organic acid content, especially in the young tissues (29, 67). The significance of these acids, which include oxalic acid, in the metabolism of the plant and the effect on animals grazing it has not been determined.

In a comparison with *Chloris gayana* and *Paspalum plicatulum* under nitrogen fertilization (90) Nandi had higher N contents than did either of the other species, with differences greatest in the leaf blades and least in the stems. Since yields of dry matter



for Nandi were lower due to lodging, the differences noted could have been due to dilution effects. In another study at Samford Nandi had the lowest N content of eleven grasses studied but also had the highest yield (104). Grazing animals at Samford consistently selected a diet with higher N content on paddocks of Nandi than those on Rhodes grass although whole plant N was similar (102). The higher leaf nitrogen contents of Nandi could explain these differences.

Within setaria strain differences in leaf, sheath and stem nitrogen contents have been found in S. Africa (142). In Queensland five contrasting introductions ranged in mean leaf N% from 1.9 to 2.6% (Henzell unpublished data). Selection of lines with high N content therefore appears feasible (142).

In comparison with data published for temperate grass species the calcium and sodium values for setaria are low and that for potassium high (173, 176, 178). Within setaria introductions from E. and S. Africa the sodium contents varied greatly at the five week regrowth stage but the contents of the other elements studied showed lesser differences (Table 1). The very low sodium values for Nandi compared with Kazungula have been confirmed in other experiments (R. J. Jones, unpublished data). There is experimental evidence to suggest that animal production is not always limited by low sodium intake on Nandi although the levels encountered are well below the N.R.C.'s recommendations (R. J. Jones, unpublished data).

TABLE 1

*The composition and digestibility of Kazungula setaria P1191 pasture on a moisture free basis (176).*

(a) Composition										
Period	Height (in)	Moisture	Protein	Fat	Fibre	Ash	N.F.E.	Ca	P	K
1. 2-8 Mar. '48	8	87.1	16.9	4.6	27.8	15.3	35.5	0.46	0.23	4.15
2. 9-15 Mar. '48	12	86.0	15.3	4.9	28.0	15.6	36.1	0.46	0.21	4.29
3. 16-22 Mar. '48	17	86.1	16.7	4.9	29.2	12.9	36.2	0.42	0.19	3.51

  

(b) Digestibility*						
Period	Dry Matter	Protein	Fat	Fibre	N.F.E.	Organic Matter
1. 2-8 Mar. '48	71.8	77.3	64.4	74.1	74.6	74.5
2. 9-15 Mar. '48	69.5	75.9	66.7	72.0	73.5	72.9
3. 16-22 Mar. '48	71.3	77.4	70.2	74.0	74.3	74.5

\* Determined with sheep.

In Nandi the soluble carbohydrate contents have been consistently low—usually below 6% of the dry matter (102) but this may be a feature of many tropical grass species.

Published values for digestibility of setaria are few. In the review of Butterworth (52) setaria compares favourably with other tropical grasses and appears to be better than many. Very few species of tropical origin attain 70% digestibility at any stage of growth but values of 70% and 72% dry matter digestibility have been reported for setaria in S. Africa (176, Table 2) and the Congo (149), and also in Australia (J. B. Hacker, unpublished data). Even so, as the S. African workers indicate, this is well below the value attainable for winter growing cereals.

TABLE 2

The chemical composition and in-vitro digestibility of several setaria accessions grown at Samford, S.E. Queensland. (Five-week-old regrowth material 11.5.67.) (Unpublished data of the authors).

Setaria strain	Element								In vitro digestibility D.M.	
	N %	P %	K %	Ca %	Na %	Mg %	Cl %	Cu* PPM	%	
Nandi .. ..	1.39	0.26	3.38	0.15	0.03	0.19	0.88	18	60.5	
Kazungula ..	1.27	0.24	4.13	0.27	0.31	0.21	0.88	26	63.0	
Bua River ..	1.08	0.23	3.87	0.18	0.28	0.16	1.03	27	63.4	
<i>Setaria trinervia</i> ..	1.15	0.25	3.68	0.19	0.03	0.21	0.86	15	62.2	
<i>S. splendida</i> .. ..	1.36	0.33	4.94	0.20	0.06	0.18	1.14	22	69.0	

In Trinidad the digestibility of 68.2% for Nandi at 4 weeks regrowth (the only stage comparable with all the other species tested) was better than the values for *Cynodon dactylon*, *Cynodon plectostachyum*, *Digitaria pentzii*, Pangola and *Brachiaria ruziziensis*. Only *Brachiaria decumbens* had a higher digestibility. Digestibility at 6 weeks was also higher than that of *C. dactylon*, the only species with which it could be compared. At 6 and 8 weeks regrowth the digestibility was similar 56.5% and 56.3% and much lower than the four week old regrowth (80).

Chemical composition and digestibility are only two aspects of the assessment of nutritive value. The third, voluntary food intake, is equally important if not more important. In Queensland the digestibility of tropical grasses, including setaria, was poorly correlated with intake (124) but workers in Trinidad claimed a highly significant correlation for these parameters (80). However, only 32% of the variability in intake was accounted for by differences in digestibility in their work.

Values for intake of setaria are fewer than those for digestibility and meaningful comparisons with other species are few. In the Trinidad work quoted above the studies with Nandi were conducted at a different time of year than the other species except *Cynodon dactylon* and at different regrowth intervals. At the four week regrowth stage when all species can be compared, only *C. dactylon* had higher digestible energy intakes than *S. sphacelata* of the seven grasses studies (80). There was a rapid fall in intake with the 6 and 8 week regrowth material but intake might have been influenced by the low values of crude protein at these growth stages (80). In the Queensland study, intake of 102 day regrowth material was half that at 52 days but again the crude protein content was below 4%. Intake of the 52 day old material of Nandi was similar to that of Kikuyu grass and Pangola and Buffel grass of the same age when fed as chaff and higher than all the others when fed as pellets. Grinding and pelleting increased the intake from 47.6 to 73.2 g/W<sup>0.75</sup>/day but reduced the digestibility from 55.8 to 50.9% (125). With the 102 day old regrowth the respective values for chaff and pellets were 28.5 and 54.5 g/W<sup>0.75</sup>/day and 48.0 and 35.6% D.M.D. (125).

Differences in digestibility and intake between the different setaria lines used in agriculture have not been reported but work by the authors indicate that at Samford *S. splendida* has a higher *in vitro* digestibility than either Nandi or Kazungula or *S. trinervia* irrespective of season of the year (see Table 1).

Animal production from setaria has been assessed in only a few trials. In Kenya (20) liveweight gain from three species over two years on pastures not fertilized with nitrogen and without an effective legume were—Nandi setaria 297 and 170 lb./acre, Nzoia Rhodes grass 327 and 195 lb./acre and Molasses grass 327 and 116 lb./acre. In Rhodesia steers grazing forage of several species in the dry season gained weight on Kazungula setaria (+48 lb./head) and on Sabi panicum (+51 lb./head) but lost weight on Katambora Rhodes grass (−37 lb./head) and on *Eragrostis curvula* (−80 lb./head) over a 118 day period (19).

Also in Rhodesia with Kazungula, the use of 120 lb. N per acre increased live-weight gains from 155 to 259 lb. per acre (means for 3 seasons), the increase being due rather to the larger number of animals on the fertilised pasture than to greater gains per animal (169).

On hay made from Nandi setaria and Samford Rhodes grass at Samford, Queensland (94), cattle merely maintained weight but gained weight if the hay was chopped or ground and pelleted. There was no significant difference between the species but liveweight gains on the hay treatments were 0.18 lb./day and on the pellets 0.78 lb./day.

Hereford steers continuously grazing these same species fertilized with 300 lb. N/acre/annum at Samford at 1 steer to 0.5 or 0.67 acre gained a mean of 509 and 462 lb./acre/annum on Nandi at the two stocking rates and 473 lb./acre/annum on the Samford Rhodes grass (99, 100, 103). In the first two years the animals on Nandi gained significantly more weight at the high stocking rate than did those on the Rhodes grass.

No significant differences were found between Kazungula setaria and commercial Rhodes grass at Samford in terms of milk production per head with no restriction on feed availability. Average daily milk production was, however, significantly higher on 3 week regrowth than on 5 week regrowth for Kazungula (88).

At Kitale, Kenya, 400 gallons of milk/acre have been recorded in 8 months on a Nandi setaria/*Trifolium semipilosum* pasture grazed at an intensity of one beast to 0.9 acres (110).

#### FROST TOLERANCE AND WINTER GROWTH

In the sub-tropics of Australia where setaria is grown, frosting is widespread (60) and can cause complete death of the above ground parts of the plant so causing a cessation of growth and possibly a loss of feeding value. On dry frosted setaria cattle have maintained weight over winter whereas in a wet winter following frosting cattle can lose up to 1 lb./head/day over the three month winter period at Samford (99). The cultivars currently available in Australia (Nandi and Kazungula) have only a slight degree of frost tolerance (22, 99) and a single frosting can have a marked effect on protein content and herbage regrowth (76). Repeated frosting can completely kill Nandi and this has occurred in the field in S.E. Queensland (105). Certain introductions from E. Africa showed considerably more frost tolerance than either Nandi or Kazungula (174). This promoted a collecting expedition by one of us (R.J.J.) in 1963. A large number of setaria collections was made but only those from a limited area in the northern Aberdare region of Kenya combined good frost tolerance with reasonable yield (83, 98, 100). These introductions have shown good leaf and plant survival in S.E. Queensland (107) and also at Berry in New South Wales (129). They are also more palatable and leafy than the commercial cultivars (106). Providing persistence and summer growth is reasonable the frost tolerance of these introductions will be of value in providing better standover feed in coastal areas of Queensland and New South Wales which are subject to frosting. Their impact on pasture development in these areas will depend on their ability to persist in the field and to produce higher yields of animal product than the existing cultivars.

#### FLOWERING AND SEED PRODUCTION

Flowering heads of Nandi are produced over a prolonged period in an undisturbed crop—in Kenya, this phase extends over a period of some five months but with a peak some 6 weeks after commencement of head emergence (41). In Australia flowering varies markedly depending on strain and species and area of origin. The latest flowering in the Brisbane area are the *Setaria splendida* accessions (J. B. Hacker, unpublished data). Kazungula flowers up to one month later than Nandi, and has a more pronounced flowering peak (22).

Setaria is almost entirely cross-pollinating though self pollination occurs in some strains (77, 78) and isolation is necessary for seed production. Crosses between strains

with different levels of polyploidy may also occur in the field (84) and such strains should still be isolated to ensure seed purity.

In Kenya yields rarely exceed 300 lbs./acre of 25% pure germinating seed (41). In Australia problems of seed production have been largely overcome and yields of 150 lbs./acre are recorded (138). The low seed yields and poor germinability of setaria and other tropical grasses when compared with temperate species is at least partly responsible for high seed prices. *S. splendida* is of very low fertility (83, 168) but may be propagated vegetatively (38, 65, 128, 150). However, there are reports of a strain of *S. splendida* selected in Kenya which may be established from seed (168), although no commercial seed supplies are available in Kenya or elsewhere.

The "seed" of setaria consists of the caryopsis and enclosing lemma, palea and glumes (39), and it is frequently difficult to ascertain whether a "seed" contains a caryopsis. Germination is generally low even in commercially cleaned samples of setaria seed, and drops rapidly unless stored in cool, dry conditions (44% to 2% germination in 12 months (103)). Also freshly harvested setaria seed carries a germination inhibitor which may be removed by a sweating process or by storage for two months (165). Studies in Kenya have shown considerable improvement in the germination of commercial supplies of seed from cross pollinating grass species such as setaria, while apomicts such as molasses grass did not show this trend. This is presumably due to unconscious selection which would not be effective in the apomict (30).

#### CYTOLOGY AND BREEDING

With the confusion that exists in the taxonomy of the *S. sphacelata* complex, some caution is necessary in reviewing reported chromosome numbers. The genome number  $s \times = 9$ , and  $2x$ ,  $4x$ ,  $5x$ ,  $6x$ ,  $8x$  and  $10x$  accessions have been introduced to Australia (82). The cultivars Nandi and Kazungula are diploid ( $2n = 18$ ) and tetraploid ( $2n = 36$ ) respectively. Table 3 lists chromosome numbers reported for the four species.

Hybrids have been produced between different species at the same level of polyploidy and full chromosome pairing at meiosis indicates a lack of extensive chromosomal differentiation in the complex (85). Chromosome pairing in  $4x \times 6x$ ,  $6x \times 8x$ ,  $8x \times 10x$ ,  $6x \times 10x$  and  $4x \times 8x$  hybrid combinations showed that the complex is an autopolyploid series (86). Attempts to produce a triploid hybrid ( $4x \times 2x$ ) have not been successful (86), perhaps due to genetic imbalance. Accessory chromosomes occur at several levels of polyploidy, but have little noticeable effect (87). Data suggest that the incompatibility system in setaria is of the two locus genephytic type common in the Gramineae (119).

Setaria is mainly cross pollinating, and considerable variation exists both within and between strains. Recurrent selection within Nandi has led to the production of improved Nandi which is leafier and earlier flowering than the original variety (33, 40). However, it has not been demonstrated as being consistently more productive (127) and no data on animal production has yet been reported.

Interest has also been shown in breeding new varieties in South Africa. Attempts to cross *S. sphacelata* with the annual *S. italica* were not successful (78), but there is evidence that selection for fertility (78), leafiness and crude protein percentage (142) within the *S. sphacelata* complex is feasible. Attempts to breed for resistance to the organism *Sphacelotheca setaria* in the Congo have met with some success (27) and indicate that disease resistance is controlled by non-dominant genes.

Possibilities of hybridisation within the complex exist (34, 85) and may lead to the development of improved varieties. However, although hybridisation between different ploidy levels may be carried out, and fertile progeny result (86), this procedure is unlikely to be used in breeding of setarias until all the variation within a level of polyploidy has been exploited.

In Australia plant breeding objectives are frost tolerance, autumn, winter and spring growth, high intake combined with high digestible energy potential and in *S. splendida*, fertility. Early work relied on natural selection under grazing (97), but with the introduction of a wider gene pool (98), hybrids are now being produced between frost tolerant strains and more vigorous Kazungula types, and recurrent selection of the progeny under regular cutting or grazing management may yield improved strains. There is also a suggestion that digestibility may vary within the complex, particularly at the mature stages of growth and improvement in this character may be possible (106). However, while emphasizing qualities such as digestibility and frost tolerance, it is essential that persistence is not lost, as this character is the major attribute of any perennial pasture species.

### DISEASES AND PESTS

There are a number of fungal parasites which may attack setaria, but *Piricularia trisa* is the only disease so far noted in Australia (22, Alcorn, pers. comm.). Under hot, humid conditions this may cause severe leaf spotting on Nandi, but it rarely attacks Kazungula (22).

In Kenya, the bunt *Tilletia echinosperma* can devastate seed crops (22, 35) and no source of resistance has yet been found (33). The disease has not been reported elsewhere and it is unlikely that it will become a problem in Australia as it can only spread from one open flower to another. The inflorescence diseases *Sphacelotheca setaria* and *Fusarium nivale* var. *majus* are a problem to seed production in the Congo, but sources of resistance are available (27). No virus disease has as yet been reported on setaria.

Army worm, locusts, etc., are pests common to all grasses in the tropics, but there are no serious pests peculiar to setaria.

### THE FUTURE OF SETARIA IN AUSTRALIA

The two strains of setaria at present commercially available in Australia—Nandi, first used commercially in 1961 and Kazungula released in 1962—are becoming increasingly popular along the moderately high rainfall coast from northern New South Wales to the Atherton Tableland in Northern Queensland. From a survey by the Seed Merchants Association in 1969 a total of 20,410 pounds of Nandi and 23,560 pounds of Kazungula seed were sold by recognised seed merchants in 1968. Because of drought conditions during 1968 the supply of seed was unable to meet the demand by farmers and graziers. Excluding private sales of seed it would appear that sufficient seed was sold by seed merchants in 1968 to plant some 20,000 acres. Information from the Queensland Department of Primary Industries indicates that an additional 50,000 pounds of seed was obtained from private sources and from outside the State. The total area sown in 1968 would therefore be at least 40,000 acres.

The spread of these varieties is as sure an indication of their value as are the results from experimental work reviewed here. Their main advantages are their ability to establish from seed, persistence under grazing on a wide range of soils, palatability, relatively high yields of digestible energy, at least in the younger growth stages, some cold tolerance coupled with early spring growth and response to fertilizer application.

Their disadvantages are susceptibility to frost in low lying or otherwise frosty areas, the requirement of above about 30 inches rainfall for persistence and good production and comparability problems with summer growing associat legumes.

Perhaps not so obvious an advantage in setaria is its cross-pollinating breeding system. In consequence, there is considerable variability within the species in the complex, and this may be manipulated fairly readily by the plant breeder. Thus characters such as frost tolerance, present in some introductions from Kenya, may be incorporated in high yielding summer growing varieties by hybridisation and selection. In addition,

the variability present in any stand of setaria gives it a tolerance of fluctuating environmental conditions which would not occur in an inbreeder or an apomict.

There is a great need to assess critically the differences between strains of setaria, to define more clearly the areas where each cultivar is best suited and to compare their production in terms of animal product with other grasses both when grown with legumes and when fertilized with nitrogen. As with most results from pastures in the tropics there is too much subjective comparison and insufficient data on which to base objective comparisons. It is to be hoped that more critical data will be forthcoming from experiments from which the ecological limitations and the productivity of this interesting and variable complex can be assessed.

TABLE 3

*Chromosome numbers in the Setaria sphacelata complex*  
Numbers in the table refer to authors

Species	Chromosome numbers					
	18	36	54	63	72	90
<i>S. sphacelata</i> *	.. 97, 159, 160, 171	97, 126, 135, 159, 170, 172	97, 126		86	86, 97
<i>S. anceps</i>	.. 85, 86	85, 86	85, 86			
<i>S. trinervia</i>	.. 85, 86, 152		85, 86			
<i>S. splendida</i>	..	85	85, 172	126		

\* Many of the references to chromosomes number in *S. sphacelata* probably refer to *S. anceps*.

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