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Climate, nitrogen and grass. 7. Comparison of production and chemical composition of Brachiaria ruziziensis and Setaria sphacelata grown at different temperatures

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Summary

In order to test the validity of previous results, a trial was performed in greenhouses on the effect of temperature, age and nitrogen level on production, morphological and chemical composition of *Brachiaria ruziziensis* Germain & Evrard and *Setaria sphacelata* (Schum) Stapf & Hubbard.

The two grasses were equally productive, but *Setaria* had a lower optimum temperature. *Brachiaria* was leafier than *Setaria* and had higher contents of nitrate and protein; it was also more digestible both because of a better digestibility and a lower content of the cell-wall constituents. It had higher contents of cations (C), inorganic anions (A) and organic acids (C-A), but its oxalate content was lower both in leaves and in stems. Leaves of *Brachiaria* were much richer in nitrate than those of *Setaria* at the same protein content.

At a greater age, both grasses had higher yields that originated from a greater number of heavier tillers. Plants were less leafy; nitrate and protein contents, and digestibility of organic matter were lower, but percentage of cell-wall constituents was higher.

Increase of temperature stimulated plant development in both grasses, causing lower protein content and lower digestibility of organic matter in leaves and stems. Temperature also had a direct negative effect on stem digestibility apart from its effect via stem development.

Nitrogen application increased production, nitrate and protein content in both grasses, but had hardly any effect on plant development and digestibility.

Consequently, *Setaria* reacted similarly to environmental conditions as the other tropical grasses studied in this and previous trials, so confirming the conclusions.

Introduction

In a series of published trials, we had investigated the effect of some climatic factors, nitrogen fertilization and age on yield, chemical composition and nutritive value of some temperate and tropical grasses. In most tropical grasses, research was limited to the effect of temperature (Deinum & Dirven, 1973). Only in trials with *Brachiaria ruziziensis* and *Axonopus compressus* Beauv. more factors were investigated (Deinum & Dirven, 1972, 1975). *Axonopus* is an important plant species of the native grasslands of the humid tropics. Its yield is, however, low, though it is suitable for lawns and sports fields.

However, to test the validity of the results collected with some of the tropical grasses, another trial was done in 1967 in which *Setaria sphacelata* and *Brachiaria ruziziensis* were grown in various environmental conditions. *Setaria* was selected since this cultivated grass belongs to a group of species that may produce well at higher latitude and altitude. According to Davies (1965), it can produce herbage of 3 to 4 % nitrogen and potentially is as nutritious as cool-temperate species. However, it is an exceptional species since it may accumulate ammonium (Birch et al., 1964) and oxalate (Jones & Ford, 1972).

The trial was performed with almost the same variables as the 1966 one (Deinum & Dirven, 1975). *Brachiaria* was again included as a reference species, since the variable solar radiation from day to day could cause differences in chemical composition (e.g. soluble carbohydrates) when the plants were grown in greenhouses.

Material and methods

The trial was done in the temperature-controlled greenhouses of the Department of Field Crops and Grassland Husbandry.

The plants of *Setaria* were grown from seed of the cultivar Nandi 1 K 53175 from Kenya, whereas plants of *Brachiaria* were collected by vegetative propagation of stock from former trials. During the trial, both grasses were grown at 3 temperatures and 2 levels of nitrogen fertilizer during regrowth periods of 18 and 35 days.

By mid April, the grasses were planted in 5-litre plastic pots filled with sandy soil (13 tillers per pot). By 9 June, after establishment of the micro swards, the tillers were clipped to about 4-cm stubble height and allowed to regrow in 3 greenhouses with day/night temperatures of 23/18, 29/23 and 31/27 °C (T1, T2 and T3, respectively).

All pots were fertilized abundantly with minerals except nitrogen, which was given at two levels: N1 and N2 (Table 1), of which N2 was considered abundant.

The trial was conducted at natural daylength (about 16 h) and at about 80 % of outdoor light intensity. Average total radiation outside the greenhouse was 1680

Table 1. Amount of nitrogen applied (g N per pot).

Growth period	18 days		35 days	
	N1	N2	N1	N2
Brachiaria	0.70	2.80	2.10	6.30
Setaria	0.49	2.03	1.47	5.25

J cm^{-2} day^{-1} during the first period (18 days) and 1701 J cm^{-2} day^{-1} during the second period of the trial (17 days). Average relative humidity was about 80 %.

The pots were watered adequately and water consumption was measured. After 18 days, 10 pots of each treatment were harvested and after 35 days another 6 pots. The herbage was dried at 70 °C and separated into leaf blade and leaf sheath + stem, and the number of tillers was counted. After grinding the samples of leaf blade and leaf sheath + stem, they were analysed for content of nitrogen (total N), nitrate-nitrogen (NO_3-N), ash, water-soluble carbohydrates (wsc), crude fibre (cf), and cell-wall constituents (cwc) and true digestibility in vitro of organic matter (D_{om}). The latter two estimates were made according to the procedures of Van Soest (cited in Deinum et al., 1968). Of these constituents, organic nitrogen was calculated as (total N) – (NO_3-N) and digestibility in vitro of cell-wall constituents (D_{cwc}) from D_{om} and cwc (D_{om} usually is about 13 percentage units higher than apparent digestibility in vivo of organic matter).

The samples of the final harvest were analysed too for K^+, Na^+, Mg^{2+}, Ca^{2+}, $H_2PO_4^-$, SO_4^{2-}, Cl^-, which were expressed in milli-equivalents per kg dry matter (meq/kg), allowing calculation of total cations (C), inorganic anions (A) and organic acids (C-A).

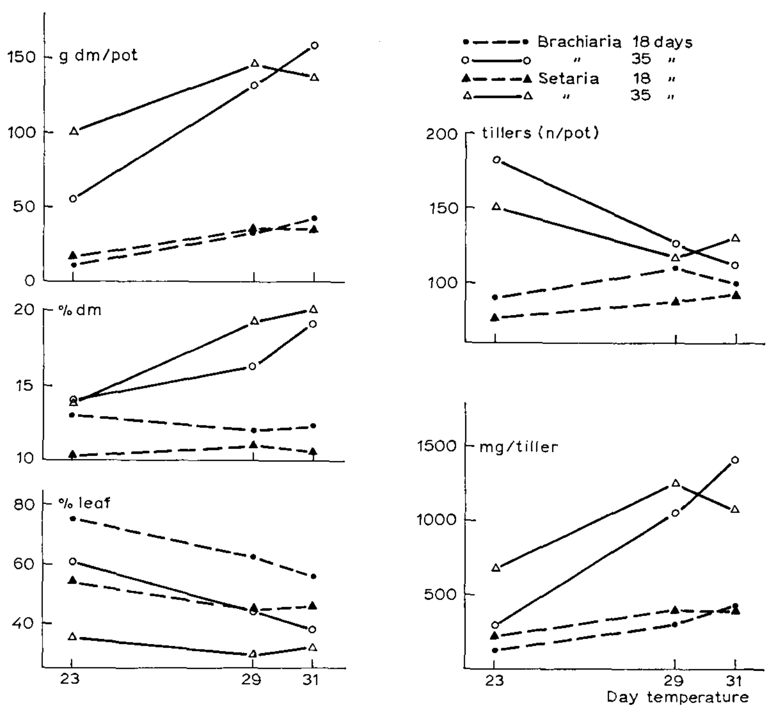

Fig. 1. Effect of temperature and age on yield of dry matter and morphological composition of the two grasses (N2 treatment).

Table 2. Effect of nitrogen fertilizer on yield, morphological characteristics, and water consumption of *Brachiaria* and *Setaria* (averages of the age and temperature treatments).

	Brachiaria		*Setaria*	
	N1	N2	N1	N2
Herbage yield (g dm/pot)	61.3	71.7*	61.8	78.2**
DM (%)	15.0	14.5	15.3	14.2
Leaf blade (% of herbage yield)	53.2	56.3	38.3	40.4*
Number of tillers/pot	110	119	97	108
Dry matter/tiller (mg)	54.6	60.2*	59.0	66.8
Water consumption (g/g dry herbage)	225.5	216.0*	230.0	214.0
Water consumption (g/g fresh leaf blade)	65.7	57.2*	98.2	81.7*

* $P > 0.95$; ** $P > 0.99$.

Results and discussion

Production, morphological composition and water consumption

Fig. 1 shows the effects of temperature and age on both grasses at the N2 level. Table 2 shows the average effect of nitrogen application. They demonstrate that the average yield of *Setaria* is somewhat higher than of *Brachiaria.* This was certainly caused by the rather high yield of *Setaria* at the lowest temperature. Yield of grass was stimulated by length of growth period, temperature and nitrogen, of which the first two factors were most important in this trial. Especially in *Brachiaria* with the 35-day treatments, the temperature effect is dramatic. However, for *Setaria* the optimum temperature regime was T2 (29/23 °C), whereas it produced still very well at T1 (23/18 °C), which agrees with its subtropical character.

Production of root dry matter per pot was much greater for *Setaria* than for *Brachiaria* in this trial (average 18.0 and 7.7 g, respectively, with the 35-day treatment).

Content of dry matter in the herbage was about the same for the two grasses. It increased with the length of the growth period and with temperature, both being presumably the result of a shortage of nitrogen, concomitant with the increasing herbage yield.

Brachiaria appeared to be leafier than *Setaria.* This may be related to the faster development of *Setaria,* which showed a higher proportion of flowering culms than *Brachiaria.* The contribution of the leaf-blade fraction to the total herbage was stimulated somewhat by the higher level of nitrogen fertilizer, but it decreased considerably with age, as expected. Percentage leaf blade of *Brachiaria* was greatly reduced by higher temperatures, but in *Setaria* this effect was less pronounced. Percentage leaf blade seemed to be well correlated with yield.

Total herbage yield is the product of tiller number and average tiller mass. *Brachiaria* produced more tillers than *Setaria,* but tiller mass of the former was less. Tillering was only accelerated by a low temperature at the longer growth period in line with other results (Deinum & Dirven, 1972), but contrary to the results of Wilson

& Ford (1971). This discrepancy may be due to the details of the trial (small swards or seedlings). Tiller mass showed similar trends to herbage yield.

Average water consumption per unit mass of dry herbage was about the same in *Brachiaria* and *Setaria*. It was most efficient with the N2 treatment and with the long growth period. In *Setaria* only, a low temperature seemed favourable. Water is mainly transpired by the leaf, so transpiration per unit area of leaf would be a better criterion. So, if leaf area per unit leaf blade fresh mass is constant, and leaf blade and leaf sheath + stem have the same dry matter content, an estimate can be made of the water consumption per unit mass of fresh leaf. After these assumptions, water consumption per unit mass of fresh leaf seemed most efficient in *Brachiaria*. Furthermore, this water consumption was less efficient with a high temperature, a low nitrogen level and a long growth period, the last presumably because of greater mutual shading of the leaves in the heavier crop.

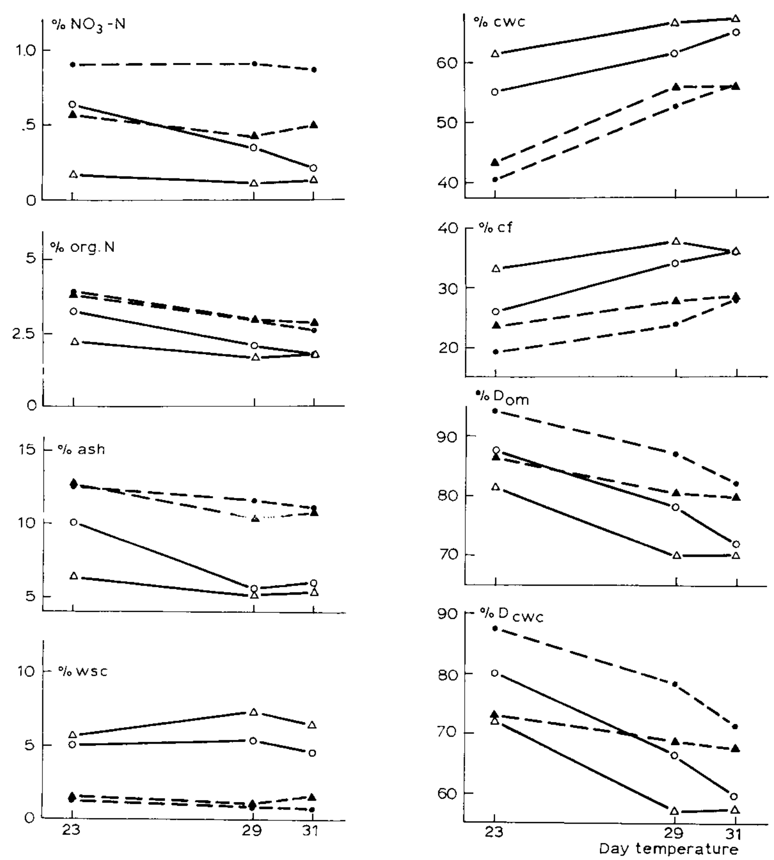

Fig. 2. Effect of temperature and age on the chemical composition of the two grasses (N2 treatment, for key see Fig. 1).

Table 3 Effect of nitrogen fertilizer (N1, N2) on chemical composition of leaf and stem of *Brachiaria* and *Setaria* (averages of the age and temperature treatments).

	Brachiaria						*Setaria*					
	leaf		stem		total herbage		leaf		stem		total herbage	
	N1	N2	N1	N2	N1	N2	N1	N2	N1	N2	N1	N2
% NO_3^--N	0.27	0.55	0.50	0.79	0.35	0.64	0.05	0.13	0.13	0.47	0.09	0.31
% org. N	2.97	3.45	1.40	1.84	2.24	2.75	2.69	3.68	1.26	1.73	1.82	2.53
% ash	11.4	10.6	9.5	8.2	10.4	9.5	9.4	8.7	8.4	8.5	8.7	8.5
% wsc	2.0	2.8	3.2	3.5	2.7	3.0	3.2	3.2	3.7	4.4	3.5	4.0
% cwc	49.4	47.3	65.4	64.3	57.4	55.1	54.3	48.6	69.0	64.6	63.5	58.4
% cf	22.9	21.5	35.1	34.6	29.0	27.6	24.9	24.5	37.3	35.2	32.7	31.0
% D_{om}	87.2	87.8	78.6	79.1	82.7	83.6	84.0	85.5	73.5	73.4	77.5	78.0
% D_{cwc}	77.4	77.4	71.1	70.9	73.8	73.9	73.6	72.8	65.0	62.7	67.9	65.9

Organic composition

The effects of age and temperature on the chemical composition of the two grasses grown at the high nitrogen treatment are summarized in Fig. 2. The average effect of nitrogen application is presented in Table 3, since there were no significant interactions with temperature and age.

The nitrate content of *Brachiaria* was much higher than that of *Setaria,* as found by Birch et al. (1964). This difference between the two species could hardly be caused by the difference in nitrogen application, since both obtained more nitrogen at the N2 treatment than they used. The content increased with nitrogen level as expected and diminished with age. Temperature had a slightly negative influence, possibly because of dilution of the available nitrogen over a greater amount of dry matter. Stems were much richer in nitrate than the leaves, as found by Darwinkel (1975) in several other crops and by Deinum & Dirven (1975) in some temperate and tropical grasses.

The organic-nitrogen content reacted like nitrate-N to nitrogen level, age and temperature, the last being most significant. *Brachiaria* had a somewhat higher content than *Setaria.* The average content in the two grasses was rather low, about 2.3 %, which is certainly due to the stalkiness of the herbage, especially in *Setaria.* However, content of organic N of leaves was about the same in *Setaria* and *Brachiaria,* despite the great difference in nitrate content. This phenomenon is expressed in more detail in Fig. 3, which demonstrates the great differences between species in leaf blades and the small differences in leaf sheaths + stems. This similarity in the leaf sheath + stem fraction may stress the transport function of these tissues for nitrate.

Content of organic nitrogen in leaves and stems decreased with age and temperature, although the decrease in the stems of *Setaria* with temperature after 35 days is small. This again may be related to higher stem mass at lower temperature.

The average ash content of *Brachiaria* was somewhat higher than of *Setaria.* The content was slightly diminished by nitrogen level and temperature, whereas age had a strong negative influence in both leaves and stems. Stems tended to be somewhat poorer in ash than leaves.

The content of water-soluble carbohydrates was very low in both grasses; moreover, they were almost devoid of starch. Nitrogen level and temperature did not

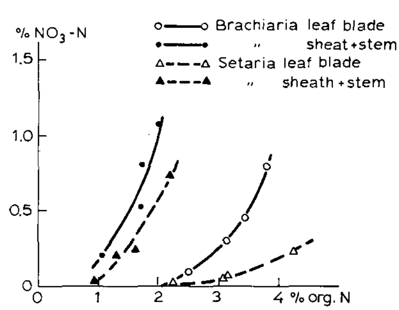

Fig. 3. Relationship between content of nitrate nitrogen and organic nitrogen in leaf blade and leaf sheath + stem in the two grasses (as a percentage of dry matter, averaged over the three temperatures).

influence the content of soluble carbohydrates, as found for other tropical grasses (Wilson & Ford, 1973; Deinum & Dirven, 1972, 1975), but contrary to temperate grasses (Alberda, 1965; Deinum, 1966). These findings are in agreement with the suggestion of Wilson (1973) that in tropical grasses, unlike temperate grasses, production (photosynthesis) and consumption (growth and metabolism) of carbohydrates are stimulated to the same extent by higher temperature. The sole significant effect was that of age, which enhanced the content. This is obviously due to the high light intensity during the 5 days before the later harvest, and the much lower light intensity during the 5 days before the first harvest. (An opposite effect of age was found in a former trial, where changes in light intensity were also the opposites.)

As to digestibility of organic matter and the factors that control it, average digestibility of *Brachiaria* was higher than that of *Setaria*, partly because of differences in leafiness, but mainly because of differences in leaf and stem digestibility. If the digestibilities for organic matter are diminished by 13 percentage units (Van Soest et al., 1966), a fair estimate is obtained of apparent digestibility of organic matter in vivo. Comparison of these data with those from literature (Soneji et al., 1971; Hacker & Minson, 1972) indicate rather high values in this trial, whereas those authors found the same advantage of *Brachiaria* over *Setaria* in digestibility. This better digestibility of *Brachiaria* coincided with a lower content of cell-wall constituents and crude fibre of leaves and stems and with a higher digestibility of cell-wall constituents.

A higher nitrogen level resulted in a somewhat lower percentage of cell-wall constituents and in an insignificant increase in digestibility of organic matter.

Both age and temperature had a negative effect on digestibility of leaves and

Table 4. Average major mineral composition in dry leaf blade (leaf) and leaf sheath + stem (stem) of the two grasses in meq/kg, (N2 treatment; harvested 35 days).

	Brachiaria			*Setaria*		
	leaf	stem	total	leaf	stem	total
g dm/pot	51.0	64.3	115.4	40.8	86.7	127.5
K^+	887	600	727	596	589	591
Na^+	13	22	18	14	13	13
Mg^{2+}	362	298	324	220	193	202
Ca^{2+}	334	206	266	247	106	151
C(cations)	1596	1125	1335	1077	901	957
Cl^-	44	36	38	29	42	38
$H_2PO_4^-$	262	149	200	153	125	134
NO_3^-	221	371	291	33	136	102
SO_4^{2-}	66	65	65	12	49	37
A (inorg. anions)	593	621	594	228	352	311
(C-A)	1003	504	741	849	549	644
Oxalate	419	144	279	822	358	509

stems, because of a positive effect on percentage crude fibre and cell-wall constituents, and a negative effect on digestibility of cell walls. The effects of age and temperature were greater in the stem fractions than in the leaves, as found before (Deinum & Dirven, 1975).

Mineral composition

The average mineral composition of leaf, stem and total herbage of the two grasses at N2 after 35 days of regrowth is presented in Table 4.

Brachiaria contained more cations and anions than *Setaria* and also more organic acids (C - A). These higher contents in *Brachiaria* may be partly due to less dilution of the available minerals over the smaller mass of herbage produced. The average mineral content of *Setaria* agreed much better with the data from field-collected samples by Hacker & Jones (1969) than with the greenhouse data of Smith (1972), who had fertilized abundantly with potassium and other minerals. However, the chloride content was very low, presumably because none was provided as fertilizer.

Brachiaria was markedly richer in nitrate than *Setaria,* as found by Birch et al. (1964), and Birch & Dougall (1967). *Setaria* may have been so low, both because of a somewhat shorter supply of nitrogen and of its capability to reduce nitrate into ammonium, which may be accumulated (Birch et al., 1964; Birch & Dougall, 1967; Smith, 1972). Because of the latter the total cation content and organic acids content in *Setaria* may have been somewhat greater than is mentioned.

As found by Birch & Dougall (1967), Jones & Ford (1972) and Smith (1971), *Setaria* accumulated moderate amounts of oxalate in the present trial, much more than *Brachiaria.* About half of it was soluble in water in both grasses, contrary to the findings of Jones & Ford (1972), where about 90 % was water-soluble. However, the contents of oxalates were much lower than found by Smith (1972), who worked with excessive amounts of nitrogen and potassium per gram dry matter produced.

Separate analysis of leaf and stem generally demonstrated higher contents in the leaves than in the stems, except nitrate which was higher in the stem than in the leaves. *Setaria* even showed extremely low contents of nitrate in the leaves, suggesting a very active system of nitrate conversion in these tissues.

Mineral contents were generally lower at higher temperature, perhaps because of dilution of the minerals over the mass of herbage, since the decrease in mineral content with higher temperature was closer related to plant yield than to temperature. The decreases with temperature were rather small or even absent in the leaves, but very pronounced in the stem fraction. Exceptions were Na^+ and Cl^- in leaf and stem, and SO_4^{2-} in leaves, which showed a slight increase with temperature in both grasses.

Relationship between chemical composition and morphological characteristics

Comparison of Fig. 1 and 2 suggests that there is some relationship between chemical composition and morphological characteristics in both grasses. This is especially true for stems. In *Brachiaria* there is a rectilinear increase in tiller mass with temperature and a rectilinear decrease in stem digestibility, whereas in *Setaria* both lines are curvilinear. The effect of temperature on stem digestibility could be mainly due

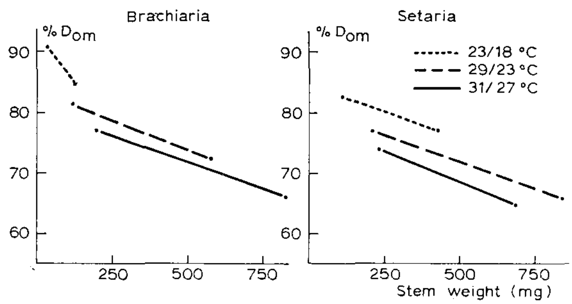

Fig. 4. Effect of stem weight and temperature on stem digestibility in the two grasses (N1 and N2 treatments combined, stem = leaf sheath + stem; the lines connect the points at 18 and 35 days of age).

to its effect on stem development. However, Fig. 4 shows that, apart from this indirect effect, temperature also has a direct negative effect on stem digestibility. It also shows that at the same mass *Brachiaria* stems were about 3 percentage units more digestible than *Setaria* stems. These direct and indirect effects of temperature not only held for digestibility of organic matter, but also for the amount and the digestibility of cell-wall constituents. This effect of temperature was also evident in the trial with *Brachiaria* in 1965 (Deinum & Dirven, 1972), but not so much in that of 1966 (Deinum & Dirven, 1975). The absence of this direct effect of temperature in the 1966 trial was almost certainly due to the low solar radiation during the second half of the growth period.

Comparison of grass species

The trial showed that *Setaria* was about as productive as *Brachiaria* on an average (Table 2; Fig. 1), but that its optimum temperature for growth was somewhat lower. This lower optimum temperature for production also holds for plant development, and is consequently reflected in the morphological and chemical composition. So leaf percentage is lowest and tiller mass highest at this temperature, whereas the organic-nitrogen content and digestibility are lowest. Consequently, much of the difference in behaviour is due to the different optimum temperature. This apart, it appeared that *Setaria* is poorer in nitrate (cf. Birch & Dougall, 1964; cf. Hacker & Jones, 1969) and richer in oxalate than *Brachiaria,* as found by others, but both constituents are only important in extreme conditions. Furthermore, both leaves and stems of *Setaria* are less digestible than of *Brachiaria.*

In *Setaria, Brachiaria* and other grasses from previous trials, a higher temperature up to the optimum resulted in a poorer forage quality: a lower organic-nitrogen content and a lower digestibility. Whether forage quality improves again beyond the optimum temperature is not certain from these trials, but is unlikely from previous trials with temperate grasses.

Furthermore, forage quality dropped with age in *Setaria* as in other grasses. Nitrogen application only improved the organic-nitrogen content and had no significant effect on digestibility in *Setaria,* as with temperate and tropical grasses in earlier trials.

Since the effects of age, temperature and nitrogen fertilizer on forage quality also hold for *Setaria,* the conclusions from earlier trials with several grasses are confirmed by the present one.

Acknowledgments

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