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Fertilizer response of cold-tolerant sorghums under semi-arid high-altitude conditions

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Summary

Five fertilizer trials were carried out over 1974 and 1975 at three different high-altitude locations in Kenya. In three of the five trials the yield response of a grain type sorghum cultivar was compared to the response of a forage type sorghum to nitrogen (N) and to phosphorus (P). In the other two trials the yield response of a grain type sorghum to N, P, potash (K) and magnesium plus zinc, boron and copper (M) was studied. Rainfall during the field period of the crop varied from 225 mm to 811 mm. There was no interaction with years, but the responses varied greatly with trial site.

Although DM yields obtained from the grain type in the driest trials were considered good, (4.9 tons DM ha^{-1} on 255 mm and 7.2 tons DM ha^{-1} on 294 mm), no response to N or P was observed.

Under wetter conditions it appeared that N increased the total DM yield of the forage type cultivar and the grain yield of the grain type cultivar: the type was accentuated. P increased the grain yield and total DM yield of the grain type cultivar. Both N and P increased the protein content of the forage sorghum, but with the grain sorghum only N increased protein % whereas P decreased protein %.

K and M had a positive influence on yield in two experiments, but more work is needed to evaluate this effect in detail.

Yield and forage quality differences resulting from different fertilizer applications were small. One possible reason for this is nitrogen-fixation in the soil, but more research is needed to substantiate this.

In the trials with the lowest rainfall, the earlier maturing grain type outyielded the forage type, but if rainfall was less limited the forage type had a clear advantage over the grain type.

Introduction

Considerable work has been done on the relationship between fertilizer input and growth response of sorghum *(Sorghum bicolor* (L) Moench). A worldwide review of recommendations is published by de Geus (1973) while Kramer & Ross (1970) discuss the accumulated knowledge on fertilizer response in America. Recommendations are low and growth response to nitrogen (N) shows more in stover than in grain production, whereas with phosphorus (P) the reverse holds true.

Sorghum can be a relatively heavy user of the major fertilizer elements and can be similar to maize in total uptake. In spite of this the crop is often grown without added nutrients. Even in America where sophisticated husbandry practices dominate, in 1964 only 50 % of the total area under sorghum was fertilized. Sorghum is often grown under marginal conditions, resulting in relatively low yields. The low usage of fertilizer is therefore due to the fact that yields are usually not high enough to be seriously limited by nutrient supply.

In highland locations of Kenya, new cold-tolerant sorghum introductions from Ethiopia and Uganda have given promising forage and grain yields (van Arkel, 1977a, 1978) and information upon the response of these sorghums to fertilizer input was required. Existing information for maize in the wetter parts of the Kenya highlands showed a good response to P, but no consistent response from N could be recorded (Sheldrick, 1974). Another study with maize under drier high-altitude conditions showed a variable response to N and concluded that increased N rates soon lead to precocious lodging, thus precluding a positive N response (Anon., 1970).

The present study was undertaken in 1974 and 1975 to examine the response of cold-tolerant sorghums to N and P fertilizer applications under semi-arid highland conditions. In 1975 an additional trial was sown to investigate a possible response interaction with applied potash (K) and magnesium plus trace elements (M).

Materials and methods

The experiments were conducted in Kenya during 1974 and 1975 at two locations of the Kenya Governments Beef Research Station (BRS) near Nakuru and at the experimental farm of the East African Agriculture and Forestry Research Organization (EAAFRO) near Athi River. A brief description of the soil at each trial site is given in Table 1.

The design for Experiment 1 was a 2 $\times$ 3^2 factorial replicated twice. This experiment was conducted at the BRS at site 1 in 1974 and at EAAFRO during 1974 and 1975. Two cultivars were used, a tall forage type cultivar, 'E 1372' at BRS and 'E 6518' at EAAFRO, and a shorter grain type cultivar, 'E 5766' at the BRS and 'E 1291' at EAAFRO. There were nine fertilizer treatment combinations (39, 91 and 143 kg ha^{-1} of N, each at 0, 52 and 104 kg ha^{-1} of P_2O_5). The N was applied as calcium ammonium nitrate (26 % N) of which half was incor-

Table 1. Brief characteristics of the three experimental sites.

Site	Altitude (m)	Distance south of the Equator (km)	Chemical analysis of the soils				Descriptive characteristics of the soils
			pH (H_2O)	K (meq)	P (mg/kg)	N (%)	
BRS (1)	1860	40	5.5	1.0	19	0.10	Soil of recent volcanic origin. Thin (20-30 cm), sandy loam topsoil overlaying murram, pumice lava mixture. Little water-holding capacity.
BRS (2)	1920	35	5.5	1.6	30	0.23	Deep sandy loam soil with good water-holding capacity.
EAAFRO	1580	157	5.5	5.5	20	0.12	Brown sandy loam topsoil, overlaying deep sandy clay subsoil. Good water-holding capacity, but subsoil has a low water permeability.

Table 2. Monthly rainfall data for the three experimental sites and two years of experimentation.

Month	Rainfall (mm) at site				
	BRS (1)		BRS (2)	EAAFRO	
	1974	1975	1975	1974	1975
January	0	4	8	6	2
February	0	10	0	9	4
March	121	19	10	114	63
April	88	123	156	119	78
May	48	66	70	30	128
June	120	88	103	42	0
July	133	95	92	35	19
August	111	89	129	12	0
September	124	153	190	1	8
October	68	94	151	8	n.d.
November	72	23	20	0	n.d.
December	10	17	23	0	n.d.

porated in the seedbed and half was broadcast as a top dressing. The P was given as single superphosphate (21 % P_2O_5) which was applied at sowing in a band 5 cm to one side of the seed.

In view of the small response obtained at the BRS in 1974, a second experiment different from the above, was designed as a 2^4 factorial. This experiment was conducted in 1975 at trial sites 1 and 2 of the BRS. The following factors and levels were used:

Nitrogen: 0 and 80 kg ha^{-1} of N
Phosphorus: 0 and 100 kg ha^{-1} of P_2O_5
Potash: 0 and 150 kg ha^{-1} of K_2O
Mineral mix (M): 0 and 300 kg ha^{-1} of the mix.[1]

N was applied as in the first experiment. P was applied as triple superphosphate (44 % P_2O_5) and banded at sowing. K (muriate of potash) and M were broadcast and incorporated into the seedbed on the day of sowing. Four plots were combined in a block and the following interactions were confounded with blocks: N×P×K and K×M. The experiment was replicated twice and the grain type sorghum 'E 5766' was used as the test cultivar.

The rainfall distribution for the five trials is given in Table 2. The trials were sown as soon as possible after the top 15 cm of the soil became wet at the start of the rainy season. This varied from between 1 April and 22 April. A plant population of 14.3 m^{-2} (70 cm × 10 cm) was attained by thinning a thickly sown stand 14 and 28 days after sowing. The plot size for all trials was 4.9 m × 5.0 m with 7 rows 70 cm apart.

For both the grain and the forage type sorghums, harvests were taken at the

[1] The 300 kg mixture contained 75 kg MgO as $MgSO_4$, 3 kg Cu as $CuSO_4.10H_2O$, 2 kg B as $Na_2B_2O_7$ and 4 kg Zn as $ZnSO_4$.

hard-dough stage of the grain. This resulted in the grain type cultivar to be harvested 33 days earlier than the forage type in Experiment 1 at the BRS (1) site. At the EAAFRO site the grain type was harvested 22 days earlier than the forage type in both years.

In all five trials, out of each plot the central 3.0 m of the middle three rows were clipped. The plants were removed as close to the ground as possible. The samples obtained were separated into morphological component parts, i.e. stem (stem plus leaf sheaths), leaves (leaf blades), and head (panicle). Of each component a sample was taken and dried in a forced air oven at 90 °C to constant weight. Dried samples were ground over a 1.0 mm screen and analysed for nutritive value. Nitrogen content was determined by the macro-Kjeldahl method. Cell wall constituents (% CWC) were determined by the Neutral Detergent Fiber method described by Van Soest & Wine (1967). The percentage of cell contents (% CC) was obtained by substracting the % CWC from 100. In vitro true organic matter digestibility (TOMD) was established by the method published by Van Soest et al. (1966). From these data the digestibility of the cell walls was computed according to: $Dig_{cell\ walls} = 100 - 100\ (100 - TOMD)\ /\ \%\ CWC$. Apparent digestibility was calculated with the regression established from the true digestibility in vitro of samples of known digestibility in vivo. Multiplication of the apparent digestibility with the organic matter content of the sample gives an estimate of the amount of digestible organic matter in the dry matter (D value).

The determination of TOMD in vitro, organic matter content and the calculation of apparent digestibility and D value was carried out by the forage quality laboratory of the Department of Crop Science and Grassland Husbandry of the Agricultural University at Wageningen. All other analyses were carried out by the forage quality laboratory of this project.

Results

BRS 1974

The total DM yield and the grain yield of the N×P experiment at the BRS (1974) are shown in Fig. 1. No significant N×P interaction was computed and N effects and P effects may therefore be considered independently. It appears from the data that N significantly increased the total DM yield of the forage type cultivar (r = 0.65***) and the grain yield of the grain type cultivar (r = 0.42*). Grain yield of the forage type and the total DM yield of the grain type were not affected by N fertilization. P significantly increased the grain yield of the grain type cultivar (r = 0.42*) and also the total DM yield of the same cultivar (r = 0.76***), but the forage type cultivar was unaffected.

The DM distribution within the plant was not altered by N or P in the forage cultivar but there was a clear and negative N×P interaction in the grain cultivar for grain % and stem % (Table 3). The leaf % was unaffected and averaged 11.2 for the grain type and 12.1 for the forage type. Hence at a low input level of one fertilizer, an increase in the other fertilizer tends to become more visible in stem growth rather than in grain formation. If the crop index is to be main-

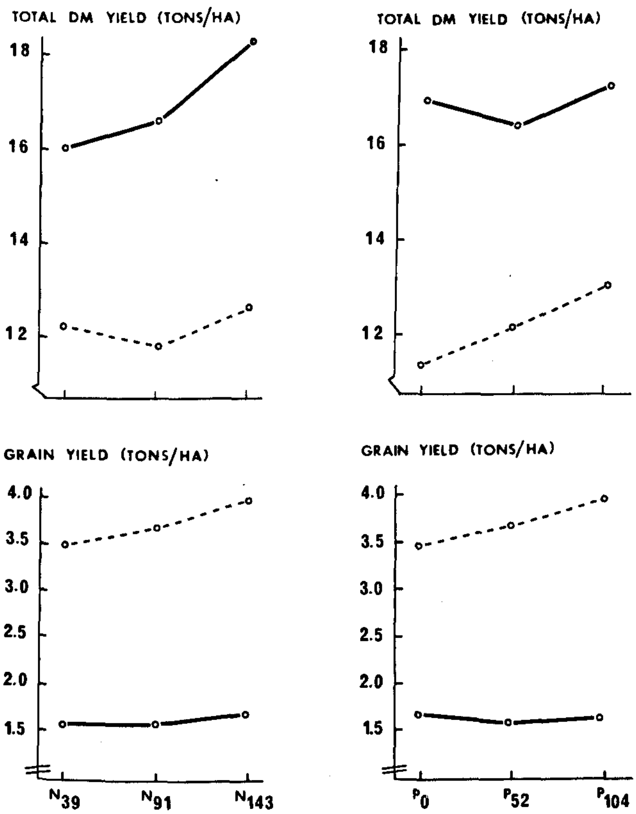

Fig. 1. Yield response of a grain type sorghum ('E 5766') and a forage type sorghum ('E 1372') to N and P fertilizer applications at the BRS in 1974. o———o forage type; o— — —o grain type.

tained or slightly increased, then N and P must be increased simultaneously.

The average protein % and the total protein yield of the total DM is given separately by cultivar and N and P level in Fig. 2. The positive correlation

Table 3. Grain % and stem % of the grain type cultivar (' E 5766') as affected by N and P.

	Grain (%)			Stem (%)		
	N_{39}	N_{91}	N_{143}	N_{39}	N_{91}	N_{143}
P_0	32.6	30.2	29.6	56.8	58.8	59.7
P_{52}	26.8	32.7	31.2	62.1	56.3	56.7
P_{104}	27.4	30.2	33.4	61.2	57.9	55.8

Source of variation:
Grain: N^{*}; P_{ns}; $N \times P^{***}$; CV = 14.8%
Stem: N^{*}; P_{ns}; $N \times P^{***}$; CV = 4.6%

* $P < 0.05$; ***$P < 0.001$; ns = non-significant.

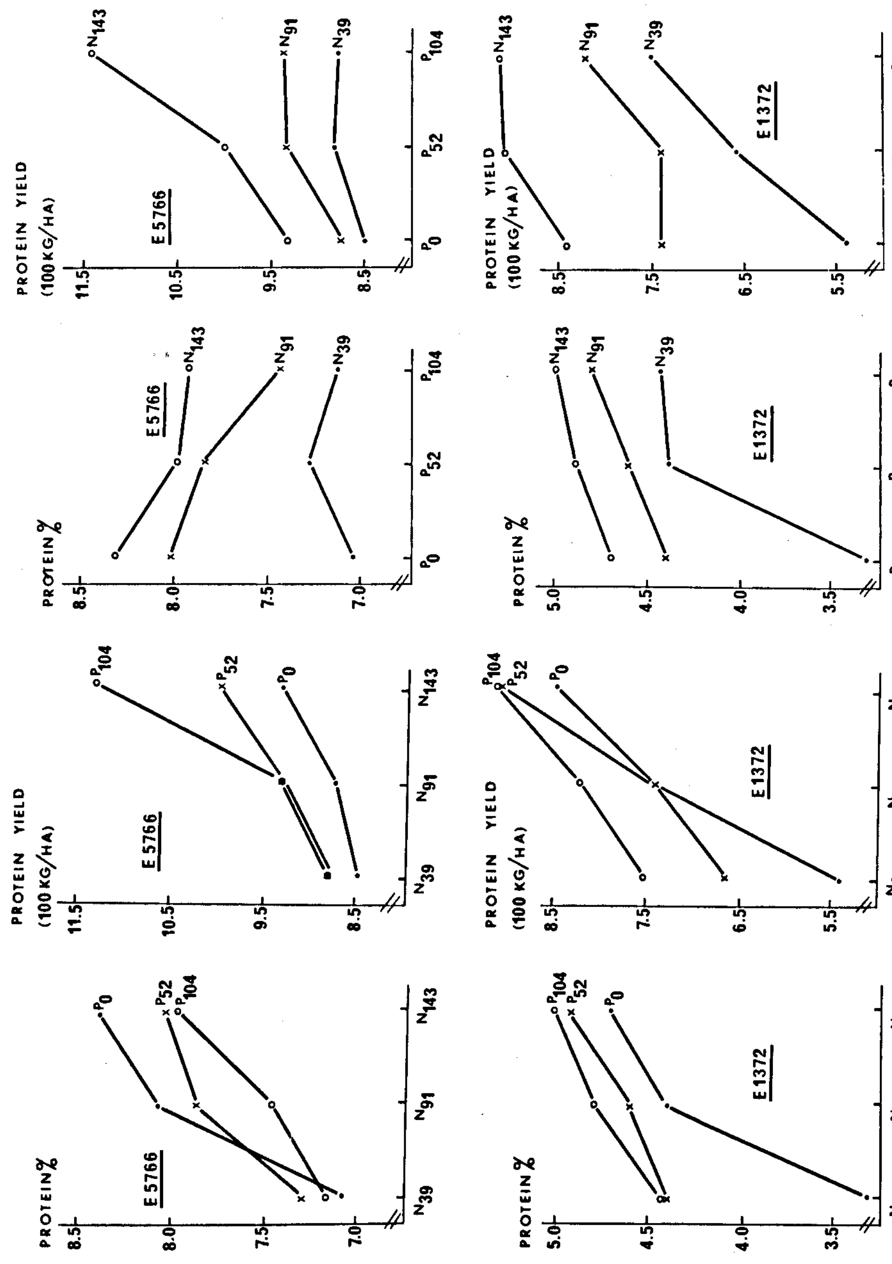

Fig. 2. Protein % and protein yield as affected by N and P for a grain type sorghum ('E 5766') and a forage sorghum ('E 1372') at the BRS in 1974.

between N and protein % is evident and so is the effect on protein yield (P <0.01). Combining the data from Fig. 1 and 2 makes it possible to calculate the N recovery percentage: 39 kg ha^{-1} added N resulted on average in 122 kg ha^{-1} N harvested, while 143 kg ha^{-1} N fertilizer resulted in 154 kg ha^{-1} N harvested. Of the additional 104 kg N, 31 % is recovered. The yield responses to N which were recorded in this trial were clear and consistent.

The effect of P on protein % and yield was less straight-forward because there was a very clear cultivar interaction. With the forage cultivar there was a positive correlation between P and protein %, but with the grain type cultivar increased P levels led to a lower protein %. This was probably associated with the positive effect of P on the total DM yield of the grain type. The nitrogen content in the forage became more diluted, hence a lower protein %.

No significant effect of N or P on the digestibility of the three plant parts could be shown. However, the differences between the digestibility of the two cultivars and their morphological component parts were considerable (Table 4). It appeared that the grain type had an average D value of 62.6 % whereas the forage type had a mean D value of 54.2 %. The higher D value of the grain type seems mainly due to three factors: (1) a higher percentage of heads in the total DM; (2) a higher digestibility of the cell wall constituens of the stem; (3) a larger proportion of the highly digestible cell contents in the heads. Ageing and the associated deposition of lignin probably accounted for the differences in digestibility of the cell walls of the stem: the forage type needed a 33 days longer growing period to reach the hard-dough stage of the grain (i.e. harvest). Difference in panicle form probably accounted for the differences in the percentage of cell contents in the head: the forage cultivar had an open panicle head with long fibrous pedicles and grains covered by large glumes, whereas the grain cultivar had a compact panicle head with small pedicles and glumes.

EAAFRO, 1974, 1975

The early cessation of the rains at the EEAFO trial site during 1974 and 1975 curtailed growth severely. In both years the trials had to be harvested before all

Table 4. Characteristics associated with the digestibility of the morphological constituents of the grain type and the forage type sorghum in 1974 at the BRS.

	Grain type				Forage type			
	leaf	stem	head	plant average	leaf	stem	head	plant average
Component (%)	11.2	58.3	30.5	100.0	12.1	78.1	9.8	100.0
True digestibility (OM)	78.3	72.7	89.7	78.5	73.3	65.7	82.8	68.3
Ash (%)	20.8	6.1	3.3	6.9	15.4	4.6	4.5	5.9
D value	52.6	57.4	76.5	62.6	53.6	52.4	69.6	54.2
Cell wall constituents (%)	56.6	57.1	28.1	48.2	65.0	58.3	45.7	57.9
Cell contents (%)	43.4	42.9	71.3	51.6	35.0	41.7	54.3	42.1
Digestibility of cell walls	61.7	52.2	63.3	55.8	58.9	41.2	62.4	45.3

Table 5. Total DM yield of a forage type and a grain type sorghum in three different trials.

Trial	Rainfall (mm)	DM yield (tons ha^{-1})	
		forage type	grain type
BRS 1974	669	17.0	12.2
EAAFRO 1974	294	6.4	7.2
EAAFRO 1975	225	4.7	4.9

heads had completed grain formation. The extremely limited moisture availability was probably responsible for the absence of any significant N or P effects. Mean yields of total DM in 1975 for the grain type was 4.9 tons ha^{-1} and for the forage type 4.7 tons ha^{-1} on a rainfall of 225 mm. This compares with 7.2 tons ha^{-1} and 6.4 tons ha^{-1}, respectively, for 1974 on 294 mm rainfall (Table 5).

BRS 1975

The average DM yield level attained in the 1975 trial at experimental site 1 of the BRS was considerably lower than the mean yield of the same cultivar obtained in the 1974 trial. Probably this was due to the fact that, in 1975, the trial was sown on a spot where the topsoil was even more shallow than at the site of the 1974 trial. The shallow topsoil and the poor physical characteristics of the subsoil contributed to the poor utilization of rain. The average DM yield was 7.4 tons ha^{-1} on 642 mm rain, which was similar to the yield of the grain type at EAAFRO 1974, but this was realized on less than half the precipitation.

Despite the low yield level, treatment effects emerged clearly. If M and K were not applied, the effects of N and P on DM yield and grain yield were comparable with the 1974 results. N had little effect on total DM yield (+ 7.5 %), but showed better in grain production (+ 18.8 %). P showed better in total DM yield (+ 17.2 %) than N and had a very positive influence on grain yield (+ 36.1 %) (Table 6). K and M had both a clear and positive effect on yield ($P<0.01$). The best treatment combination was $N_{80}P_0K_{150}M^+$ which yielded 9600 kg DM ha^{-1} of which 2213 kg ha^{-1} as grain. The necessity of zero phosphorus in the treatment combination was explained by the clear and significant

Table 6. The effects of nitrogen (N), phosphorus (P), potash (K) and the mineral mixture (M) on the total DM and grain yield of the grain type sorghum ('E 5766') at trial site 1 of the BRS in 1975.

	N_0*	N_{80}*	P_0*	P_{100}*	K_0	K_{150}	M_0	$M+$
Total DM yield (tons ha^{-1})	6.7	7.2	6.4	7.5	7.0	7.7	7.0	7.7
Grain yield (100 kg ha^{-1})	12.8	15.2	11.9	16.2	16.1	17.8	14.8	19.1

* Non-orthogonal comparison: only the data from plots where *no* K and M had been applied were used.

Tabel 7. Interaction between P and M for total DM yield and grain yield at trial site 1, BRS 1975.

	Total DM yield (tons ha^{-1})		Grain yield (tons ha^{-1})	
	P_0	P_{100}	P_0	P_{100}
M_0	6.5	7.5	1.29	1.66
M+	8.1	7.3	2.04	1.78

Table 8. Interaction between P and M for total DM yield and grain yield at trial site 2, BRS 1975.

	Total DM yield (tons ha^{-1})		Grain yield (tons ha^{-1})	
	P_0	P_{100}	P_0	P_{100}
M_0	19.4	20.1	4.73	5.13
M+	20.4	19.0	5.28	4.10

negative interaction M×P ($P<0.01$) (Table 7). It is difficult to detect which element of the mixture was responsible for the antagonism with P.

The same experiment carried out at trial site 2 resulted in very much higher average yields (Table 8). Despite this no effects of N or K could be demonstrated. The main effects of P and M were curtailed by their significant interaction ($P<0.05$), thus confirming the M×P negative interaction observed in the trial at site 1.

Discussion

Fertilizer effects on yield

The yield increase resulting from the application of nitrogeneous fertilizer was small in two trials and completely absent in the other three.

The average DM yields obtained at the relatively dry EAAFRO trial sites were high if compared with the yield one may expect to obtain from the natural rangeland vegetation (Le Houerou & Hoste, 1977), and they rank among the very highest forage yields ever obtained at this trial site under these rainfall conditions (Annual EAAFRO reports, 1963-1973). However, the severely limited moisture availability probably accounted for the lack of response and precluded a possible fertilizer effect. But another study with sorghum under similarly dry conditions in Kenya (Anon., 1965) indicated that low applications of N were beneficial, but quantities greater than 33 kg N ha^{-1} decreased yield.

At the much wetter BRS sites, DM yields were considerably higher and comparable to those recorded in other trials (van Arkel, 1977a, 1978). However, yield responses to N were also limited. In one trial, yields were totally unaffected by N and in the other two trials DM yields were increased from 7.5 –

14.6 %. The highest N recovery percentage computed was 31.

Although the low response to N fertilization has also been reported by other workers (e.g. Berra et al., 1971), usually DM yields of forage crops are increased more substantially if the N content in the soil is low and if annual rainfall is between 500 and 1000 mm (Engelstad & Russel, 1973; de Geus, 1973). Singh (1971) working with forage sorghums reported DM yield increases of up to 32 % from 67 kg N ha^{-1}. Roy & Wright (1973, 1974) working with grain sorghums under similar conditions found DM and grain yield increases of 39 and 60 %, respectively. N recovery percentages were computed to be around 61. No reports on the response of sorghum to N fertilizer, applied under similar high-altitude conditions were available for comparison. However in a study with forage grasses (*Pennisetum* spp.) at the same BRS sites, van Arkel (unpublished data) measured N recovery percentages of up to 64, which is about twice as high as the N recovery percentage measured in the present sorghum trial.

The exact explanation of the limited response to N is difficult. The possibility of other nutrients being limited in supply thus preventing N effects was disproved by the subsequent experiments in 1975. Other possible explanations such as a high organic matter content in the soil (Keogh & Maples, 1959) or increased insect and pest attacks (Martin, 1963; Rosenow, 1963) did not withstand investigation. Leaching or volatilization is not likely to have played a major role under our conditions (Engelstad & Russel, 1973).

It appears attractive to consider the possibilities of nitrogen fixation under a crop of sorghum. It has been suggested that sorghum can benefit from non-symbiotic nitrogen fixation (Dart, 1977, pers. comm.), but it is clear that more research is needed to substantiate this claim.

In the trials where N did have an influence on yield, it appeared that the forage yield of the forage type cultivar and the grain yield of the grain type cultivar were increased most: the type of the cultivar was accentuated (Fig. 1). The general inference from the results of the three experiments at the BRS is that P was the principal factor which limited the yield of the grain type sorghum. In all three experiments this element led to an increase in grain yield and total DM yield, the only exception being when magnesium and the trace element mixture was added.

Effects on digestibility

No significant effect of N or P on the digestibility of the crops was shown. This is in contrast with some work carried out on grasses elsewhere, whereby a clear positive correlation between fertilizer rate and digestibility was demonstrated (Fribourg et al., 1971).

The average D values recorded for the two cultivars (54.2 and 62.6) were well within the range of D values published by Sheldrick (1974). Working with maize grown under high-altitude conditions in Kenya, and in a comparison of different cultivars grown over several years, he found D values from 46.0 to 66.0. Wedin (1970) working with several forage type sorghums in America found D values from 52.0 to 59.1. It must be noted that maize and sorghum grown at higher latitudes in Europe tend to achieve higher D values (Sheldrick, 1971). However, the D values recorded in this study are not exceptional for sorghum grown in the tropics and also the values for component %, ash % and CC % are within the range of exceptability (McDowell et al., 1974). Particularly noteworthy is the high ash % in the leaves of sorghum (Table 4).

Despite the above, the differences in digestibility between the two types of sorghum were conspicuous. This was probably associated with differences in the ages of the crops and with differences in morphological plant composition. The forage type cultivar was 33 days older than the grain type cultivar when harvested. In grasses ageing is associated with a decreasing digestibility. This is not necessarily so with cereals with a good grain yield. Bunting & Gunn (1973) and Sheldrick (1974) have shown that in maize digestibility changes markedly little over time. The quality of the stover decreases during the grain filling period but this is compensated for by the formation of the highly digestible grain. Grasses do not have the ability of producing so much seed and therefore they cannot compensate for the loss of digestibility in the stover. It seems logical to assume that the grain type sorghum (crop index = 30.5 %) was little affected in its digestibility by age (Table 4). The forage type sorghum with a much lower crop index of 9.8 % has probably decreased its digestibility somewhat due to ageing.

In both cultivars, the head components had a substantially higher D value than the leaves and stems. It therefore seems logical to assume that this was also part of the reason that the cultivar with the higher crop index also had the higher overall D value. However, the positive correlation between crop index and crop digestibility has been questioned (Bunting & Gunn, 1973). At present work is in progress to evaluate this correlation in more detail for Kenyan conditions.

Fertilizer application as a husbandry factor

It is clear from these experiments that accurate fertilizer applications played a relatively minor role in determining yield and DM quality. More important factors appeared to include rainfall and physical soil characteristics, or weed control (van Arkel, 1977b). Differences between cultivars were also large, although there was a clear interaction between the yield difference of the grain type and forage type sorghums with rainfall (Table 5). Under the drier conditions the earlier maturing grain type had a distinct advantage over the forage type ($P<0.05$). But under more favourable growing conditions the forage type produced more DM ($P<0.001$).

The relatively unimportant role of fertilizer for obtaining good yields seems to contribute an advantage to this crop. Fertilizer is a relatively expensive commodity and the limited demand reduces the capital risk and makes sorghum an attractive crop.

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