On the seed production of tropical grasses in Kenya

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Proefschrift
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Stellingen

I

De lage zaadopbrengst van de in dit proefschrift behandelde grassen is vooral een gevolg van de grote spreiding in tijdstip van doorschieten en bloei.

II

Bij de voor dit proefschrift onderzochte grassen verhoogt stikstofbemesting het aantal bloeiwijzen terwijl nauwe rijafstand het gelijktijdig doorschieten en bloeien bevordert. Hieruit is een optimale combinatie te vinden voor de zaadopbrengst.

III

Bij goede stikstofvoorziening van de in dit proefschrift besproken grassen is de variatie in zaadopbrengst tengevolge van uitwendige omstandigheden vrijwel geheel toe te schrijven aan verschillen in het aantal kiemkrachtige zaden per bloeiwijze.

IV

Binnen de onderzochte variëteiten van tropische grassen bestaat een positieve correlatie tussen schietdatum enerzijds en groeikracht en zaadopbrengst anderzijds.

V

In de tropen handhaven weidevlinderbloemigen zich in het algemeen niet tegenover grassen. Daarom dient gezocht te worden naar meer agressieve vlinderbloemigen en niet naar zwakkere grassen, zoals door Hutton wordt gesuggereerd.

E. M. Hutton. Advances in Agronomy 22 (1970) 2-74.

VI

De gunstige verschuiving in de prijsverhouding tussen kunstmeststikstof en dierlijke produkten maakt het ook voor goed geleide bedrijven in de tropen aantrekkelijk kunstmeststikstof te gebruiken als alternatief waar vlinderbloemigen in gebreke blijven.

VII

Aan de veredelingsmethode bekend onder de naam polycross kleven meer bezwaren van zowel praktische als genetische aard dan door Lackamp zijn aangevoerd.

J. W. Lackamp. Euphytica 15 (1966) 291-296.

VIII

Ten bate van de bevolkingslandbouw in de tropen dient de tussenteelt van granen en peulvruchten bevorderd te worden.

R. W. Willey & D. S. O. Osiru. J. agric. Sci. Camb. 79 (1972) 517-529.

IX

Met het oog op een juiste internationale arbeidsverdeling dient voor de zo noodzakelijke uitbreiding van de vleesproduktie vooral gebruik te worden gemaakt van de mogelijkheden binnen de keerkringen.

X

Bij de Afrikaanse bevolking stuit het gebruik van voedingsgewassen voor veevoer op grote weerstanden.

XI

De Australiër kan zich met evenveel recht de ontdekker noemen van tropische weidevlinderbloemigen als van het wilde konijn.

XII

Volgens Gideon heeft Ulysses Vlissingen naar zich vernoemd en is hij over zee naar Circe in Zierikzee afgedreven. Om Thor Heyerdahl tijd te bieden de historiciteit van deze tocht te bevestigen dient de Oosterschelde voorlopig open te blijven.

E. Gideon. Homerus, zanger der Kelten. Deventer, 1973.

Proefschrift van Ir. J. G. Boonman
Wageningen, 30 mei 1973

Definitions and abbreviations

Yields and fertilizer rates are expressed in kg ha^{-1} $crop^{-1}$, unless stated otherwise. Wherever necessary, references are made in this article to tables (T), figures (F) or pages (P) of the above papers, indicated by their number (I-VII).

Heading tillers: these are tillers in which heads have fully emerged, the critical feature being that the base of the head should be visibly free from the subtending leaf sheath.

Crop Index: the ratio of yield of clean seed to total herbage dry matter yield.

IHE, Initial Head Emergence: stage of initial heading when 5–10 heads per m^2 have fully emerged from the subtending leaf sheath.

PGS, Pure Germinating Seed. The relevant formula is: yield of clean seed × percentage PGS = yield of PGS.

Introduction

The object of these studies was to find ways of improving the low seed yields of tropical grasses. Kenya has a well established grass seed industry and it was assumed that such studies would be of practical value.

The approach was centered on the factors affecting seed yield of species that are popular with farmers for their herbage productivity (I, T1). The most important of these are *Setaria sphacelata* cv. Nandi and *Chloris gayana* cvs Mbarara, Masaba and Pokot Rhodes.

Formerly, commercial yields rarely went above 25 kg Pure Germinating Seed (PGS) ha^{-1} $crop^{-1}$. In spite of the inevitably high seed prices (I, T3) the demand for seed has risen steadily over the past decade (I, T2).

Certain cultural practices had been adopted in the past by seed growers (I; III; IV; V; VI), although there were very few data, locally or abroad, to support these practices. There was also little information on the relative merits of the many varieties available. It was, therefore, felt necessary to adopt the following lines of approach to the problem of low seed yield:

- to analyse the mechanism of seed yield: heading, tillering and seed yield components;
- to determine the techniques of management: fertilizer, row width, seed rate and harvesting time;
- to study the effect of weather and season;
- to study and utilize the genetic variation with the aim of producing varieties with higher seed yield, without detriment to herbage productivity.

Determinants of seed yield

A schematic review of seed yield components and the important factors affecting them is given in Table 1. Figures representing absolute values are in italics, whereas non-italics are relative to 100. For comparative purposes data are included for a good seed crop in Europe of *Phleum pratense* (Timothy), a small-seeded grass with some resemblance to *Setaria sphacelata* in seed yield components. The Nandi variety of the latter species was taken as the example in Table 1, but other species and varieties were found to behave similarly.

The striking features of Table 1 are (1) the gap between the actual and potential yields and (2) the importance of management and breeding as a means to bridge this gap.

The usual yield equation for seed crops is:

yield of (clean) seed = number of heads × number of seeds per head × seed weight.

A refinement of this equation to include the PGS is needed for tropical grasses because of the low viability of the seed normally encountered:

yield of PGS = yield of clean seed × %PGS = number of heads × number of PGS per head × seed weight.

It can be seen from Table 1 that potential yields of *Setaria* are close to actual yields obtained with *Phleum pratense* in Europe, while seed yield components are also very similar. In contrast, actual yields in current varieties are only a few percent of the potential. The examination of seed yield components offers some explanation. Head numbers in the current variety are only half of those of the potential, while seed weights are similar, but the principal cause for the huge difference in PGS yields lies in the low seedsetting, defined here as the average number of germinating seeds (PGS) per head emerged, which amounts to only 15% of the potential. Although low seedsetting and low head number are partly genetical in origin, seed yields could still be quite adequate were it not that in tropical grasses seed yield components do not operate uniformly. Here lies the crucial weakness of the grasses studied and this appears to be the main cause of the low seedset observed. Head emergence is prolonged both within and between plants and flowering within heads can continue for weeks (I, T4). Seed maturation is, therefore, spread over a very long period. To make things worse, seeds tend to shed upon maturation. Thus, at any harvest date, seed losses are incurred due to shedding or incomplete seed formation in late emerged heads, while many heads may be still enclosed in their leaf sheaths.

Heading patterns primarily affect head numbers but as no seed can set in heads that emerge too late, seed set and seed weight are affected also. In an undisturbed crop, heading can continue for 2–4 months prior to reaching the maximum number (I, F1, T5; II, F1, F2; III, T6; VII, F2) although tiller numbers reach their maximum in a shorter period (II, F1); III, F2). In contrast, in bred varieties of temperate grasses at higher latitudes, heading is confined to a number of days whereas tillering has been going on for months since the previous autumn. The daylength effect, which causes tillers of very different ages to elongate and head within a few days in temperate conditions (II, P248), seems to be absent at Kitale where differences between maximum and minimum solar daylength are only 9 minutes (I,

Table 1. Scheme of the response of seed yield and its components (absolute values in italics, non-italics relative to 100)

	Yield			Yield components					Crop Index (%)
	dry matter at seed harvest (kg ha^{-1})	clean seed (kg ha^{-1})	PGS (kg ha^{-1})	number of heads (m^{-2})	number of harvested clean seeds per head	PGS (%)	number of pure germinating seeds (PGS) per head	1000-grain weight (mg)	
Current variety (Nandi), good crop	*10000*	*160*	*50*	*250*	*180*	*30*	*50*	*350*	*1.6*
Management:									
good crop	100	100	100	100	100	100	100	100	100
without N	25	8	5	15	50	60	30	100	30
N applied 4 weeks late	90	60	35	80	80	55	45	100	70
wide rows	100	80	65	90	90	80	70	100	80
harvested 1 week early	100	100	80	90	120	80	100	90	100
harvested 1 week late	100	70	80	110	55	110	60	120	70
Weather:									
favourable	100	100	100	100	100	100	100	100	100
average	100	60	40	90	70	60	40	100	60
unfavourable	100	40	10	80	50	30	15	100	40
Varietal:									
current Nandi	100	100	100	100	100	100	100	100	100
improved variety	110	150	280	190	80	180	140	100	130
potential variety	>110	500	1500	200	250	300	750	100	500
Current variety of *Phleum pratense* in Europe, good crop	—	*800*	*700*	*500*	*400*	*90*	*350*	*400*	—

P31) and heading can occur throughout the year. Any tiller that reaches the required stage is able to form a head, its time and success of emergence depending upon age and the concurrent effects from other tillers. In tropical grasses only a small proportion of tillers produce a head at seed harvest (III, F1, T3, T4; IV, T2, T4; V, T2). The highest number of tillers observed in this study was in Nandi, 2800 per m² producing 290 heads (III, F2, T6). *Panicum coloratum* cv Solai (Coloured Guinea) had the highest head number on record, 520 per m² (II, F2; VII, T1).

It is now important to see how the seed yield components respond to management, weather and breeding (Table 1) before we move on to a more detailed discussion of the various factors.

In the absence of nitrogen (N), which is evidently the most critical growth factor, all yield components, except 1000-grain weight, are greatly reduced. PGS yields drop much further (to 5%) than dry matter yields (25%), which illustrates the sensitivity of seed yield to N deficiency, partly through low head number (15%) and partly through low PGS per head (30%). With all other management factors listed in Table 1, herbage yields, head numbers and 1000-grain weight are affected only to a minor degree, i.e. less than ± 20%. The principal yield component subject to variation is the number of PGS per head. This component is primarily responsible for the reduction in PGS yield with late N dressing, wide row width and unfavourable season. With late harvesting the low number of PGS per head was compensated for by an increase in head number and 1000-grain weight, so that the ultimate PGS yield was not affected seriously.

It is further evident from Table 1 that considerable improvement in raising the number of PGS per head and, consequently, PGS yield per ha is achieved through breeding. Massive scope for further improvement still exists before yields approach anywhere near their potential.

From the above it is evident that attempts to increase seed yield should be two-pronged: (a) to maximize seed yield components and (b) to synchronize the action of each component. The effect various factors have on this will be discussed now.

Fertilizer and plant density

Nitrogen application and row width are of paramount importance as farmer's tools to increase yield. They are here dealt with together because of their frequent interaction.

As regards other fertilizers, phosphate was found to have no direct effect on PGS yields, its action being confined to promoting rapid establishment after sowing (III, IV). No deficiences of sulphur, potassium or other elements were noticed during these studies, even though some of them involved the annual removal of up to 20 tons of herbage dry matter over four to five years (III, T5, IV). Likewise seed rates even when varied from 0.2 to 1.8 kg PGS per ha (III; IV, T1) had no significant effect on PGS yield in the establishment crop or thereafter.

Nitrogen fertilizer and row width are important tools to manipulate heading and subsequent seed setting. It was found that any given crop produces more seed under conditions of close tiller density and appropriate N dressing. Tiller density should be such as to allow a high number of heads to emerge in a short time while suppressing the development and heading of late tillers (III). Stoloniferous species such as Rhodes grass achieve an optimum density of their own to some extent (IV, T1, T2), but row width is critical in non-stoloniferous species, such as setaria. It was found in Nandi that many tillers were produced at a narrow row width (III, F2) while N ensured that a high percentage of them produced a head (III, T4). At 130 kg N per ha, PGS yields were one third higher in narrow rows of 30 cm than in wide rows of 90 cm. However, increases in PGS yield due to narrow row width were often not accompanied by parallel increases in head number and 1000-grain weight and heads were invariably shorter, even in Rhodes grass (III, T3, T4; IV, T2). Thus, higher PGS yields were brought about by a better seedset, i.e. more PGS per head. One possible explanation is that seed maturation was more even at narrow row width because heading was noted to begin later (III, T3, T6, F1; IV, T2). Secondly, in short heads less competition may occur between spikelets so that more seeds mature fully per head.

PGS yields were increased sixfold to sevenfold by the application of 100 kg N per ha which appeared to be the general optimum in post-establishment crops. Levels above 100 kg gave increased PGS yields only in a few seasons with very high yields, e.g. late 1970 and 1971 (III, T2; IV, T3). In general, however, rates above 100 kg increased head numbers further, but either reduced the percentage PGS (e.g. Mbarara Rhodes (IV, T2, T3)), or percentage and yield of PGS (e.g. Nandi (III, T2, T4, F1)). Of the various possible causes (III, P32), the most likely one is that seed set is reduced in the long heads produced at high N. Though heads often look darker at high N, there appears to be more shedding in them (IV, P223).

Without N, PGS yields dropped rapidly after the establishment crop (Table 1; III, T2; IV, T3; V, T3). With low N, PGS yields were usually higher at wide row width. Conversely, wide row widths responded little to N (III, T2, T4, F1). This interaction points to the necessity of combining narrow row width and adequate N fertilizer.

Although N level is of great importance, its effect is greatly reduced when applied late in relation to the growing season and growth stage of the crop (V). N had most effect when applied to young grass early at the onset of the rains. A delay of 4 weeks decreased PGS yield by more than 60% in Nandi (V). The main seed yield component to be adversely affected by late N was the number of PGS per head (Table 1), though head numbers did decline, but not nearly as much. The 1000-grain weight was not affected if N was applied late in relation to growth stage. It, however, increased when cleaning cut as well as top dressing were delayed (V, T2). Late applied N seems to encourage late tillering and heading, probably at the expense of seed setting in early heads, without compensating for the latter (V, T5, T1). However, the date of IHE in the early-season crop was not affected by date of N application, so that heading and flowering occurred under the same weather conditions whether N had been applied early or not.

Time of harvest

Unexpectedly, Kitale grasses were found to be less sensitive to harvest date than their proneness to shedding would lead one to believe. In fact, it was found that shedding could amount to more than 30% without impairing PGS yield (VI, T3, F2). The most likely explanation for this unusual phenomenon is that it is empty spikelets that are shed early, while compensatory gains result from the late developing spikelets. The period over which harvesting can be carried out safely was on average 1–2 weeks for varieties of Nandi, Rhodes grass and Coloured Guinea, all investigated over a period of 4 years. The interval between IHE and optimum harvest date was normally 6–7 weeks.

Up until now, it seems that growers have had the habit of harvesting too early as they naturally become alarmed once shedding sets in. Although it is difficult to reproduce growers' practice, it can be assumed that some 20% of the crop potential was lost by this early harvesting (Table 1).

Weather

It was suggested that seed setting, the major variable determining PGS yield, was greatly affected by weather conditions in the pre-heading period (V). The available evidence suggests that rainfall is of critical importance. It can be seen from Fig. 1 that June is a relatively dry month and so are September and October. This may explain why early N application is crucial. It can also be seen from Fig. 1 that solar radiation and maximum temperatures drop steadily until July when they begin to rise again.

Large variations in PGS yields not only occurred within season but also between seasons and years, especially in Nandi (III, T2; V; VI, T3), though to a lesser extent in Rhodes grass (IV, T3, T4; VI, T3) and Coloured Guinea (VI, T3). In contrast, yields of dry matter were relatively constant (III, T5; IV, T4). Variation in head number was also limited, bearing no significant relation to PGS yield in a particular season (Mbarara Rhodes $r_s = +0.51$, Nandi $r_s = -0.61$). Consequently, head number cannot be used to predict PGS yield. There was also variation in 1000-grain weight from season to season, but heavy weights occurred in both good and bad seasons (VI, T3). These considerations point again to the overriding importance of seed setting as the principal determinant of PGS yield per season and, in turn, to the effect of weather.

The weather and yield data over the 5 years, i.e. 10 seed harvests, of this study, 1967–1971, show a definite relationship. In Table 2 a comparison is made between weather data for 5 harvests with above-average yields, 5 harvests with below-average yields and the long-term seasonal averages. Seasons with good yields had more rain which was better distributed

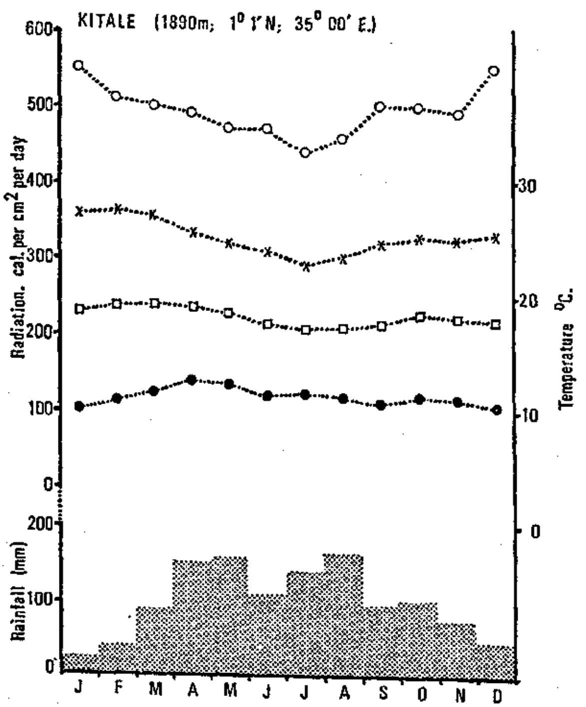

Fig. 1. Seasonal variation in energy imput, temperature and rainfall; ○……○ incoming solar radiation; ×……× mean maximum temperature; ●……● mean minimum temperature; □……□ mean temperature.

Table 2. A climatic comparison of growing seasons (April–June; July–September) over 1967–1971, at Kitale

	Number of seasons	Rainfall (mm)	Days with more than 1 mm rain	Periods with less than 5 mm rain		*Mean daily temperatures* (°C)			Daily hours of sunshine (Campbell-Stokes)	Solar radiation (Gunn-Bellani) cals cm^{-2} day^{-1}
				10-days	5-days	Max.	Min.	Mean		
Seasons with good yields	5	473	54	0.0	3.2	23.5	11.5	17.5	6.4	460
Seasons with bad yields	5	372	38	1.8	6.4	24.4	11.8	18.1	7.1	490
Average seasons	long-term	408	47	0.8	5.1	24.1	11.7	17.9	7.0	470
Coefficient of correlation with PGS yield (r_s)		+0.44	+0.80**	−0.91**	−0.55	−0.41	−0.25	−0.34	−0.54	−0.52

** $P < 0.01$.

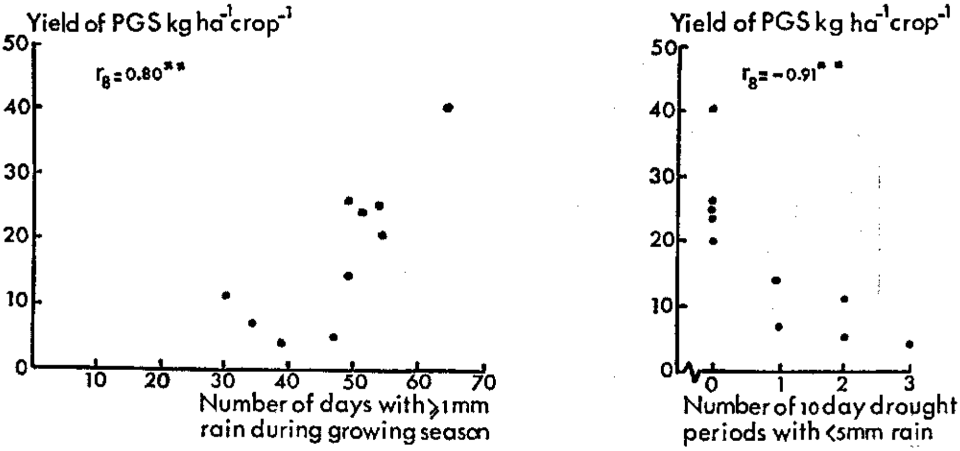

Fig. 2. The effect of rainfall distribution on PGS yield of Nandi in various seasons.

without prolonged droughts. They were also cooler with less solar radiation and fewer hours of sunshine. Considering however the correlation coefficients of Table 2 it appears that a good distribution of rainfall is the major prerequisite to achieving high PGS yield. This is further illustrated in Fig. 2. It seems that good yields are achieved if rain falls on more than half of the days of the growing season and if no drought periods occur lasting more than 10 days.

The grower can manage the crop so that early heading coincides with periods likely to have good rain. Alternatively, he may divert the crop for fodder purposes if the weather has been too unfavourable to justify waiting for the seed harvest.

The effect of weather needs further investigation, in particular to verify if rainfall in the pre-heading and, possibly, other periods is indeed of critical importance. If so, supplementary irrigation may well prove to be an economic proposition.

On the breeding side, it may be important to search for genotypes with a seed setting potential that is less dependent on weather conditions.

Genetic variation

Even though species and varieties behaved similarly in response to agronomic measures (II; III; IV; VI), they varied markedly in seed yielding potential (VI, T3; VII, T1). At the species level, *Panicum coloratum*, an early species, yielded very well, in contrast with *Panicum maximum*, cv. Makueni, although the latter is among the earliest of all Kitale varieties to come into head (II, T2). At the varietal level, the early heading varieties such as Nandi I and Mbarara Rhodes produced about twice as much as the late heading Nandi III and Pokot Rhodes, respectively. However, the medium-early Masaba Rhodes yielded almost as well as Mbarara Rhodes (VII, T1).

In the early Sixties, Nandi II and Nandi III were selected out of the original Nandi ecotype, subsequently renamed Nandi I, with the aim of developing late-heading varieties with supposedly better nutritive value. Only later did it become apparent that these late heading varieties and also those of Rhodes grass were in fact inferior not only in seed but also in total herbage production (VII).

The parental material of the above varieties had not been maintained so that each variety evolved further from one seed generation to the next. This inevitably led to genetic shift (I, T6) and a programme of re-selection was initiated in 1968, based on spaced plants collected from multiplication fields.

It was subsequently observed that these varietal populations were extremely heterogeneous in heading time, growth habit, plant vigour and head number. There was a period of 4–6 weeks between the dates of the first 5% and the last 5% of the plants to come into head (I, T5; VII, F2). Early heading groups of plants consisted largely of tall and vigorous plants with many heads. Conversely, poor plants with fewer heads made up the majority of late heading groups (VII, T2, T3, F1). Some plants produced no heads at all (VII).

In 18 clones of Nandi, grouped together on the basis of early and uniform heading, good vigour and high head number, great variation was observed as regards yield of PGS per plant, head number per plant and seed setting per head (VII, T6). Three outstanding clones had average PGS yields three times the average of all 18 clones. These three clones represent the improved variety of Table 1. Of major importance was the finding that PGS yield and its components displayed high heritability.

The high heritability and genetic gain observed for seed setting is of particular importance since this component was mentioned earlier as very sensitive to agronomic measures and weather. Seed setting is best determined by means of germination tests, however laborious they are. Weighing the clean seed is clearly not enough, because it was found (VII) that high yields of clean seed were not associated with good germination percentages (r_{78} = −0.04). Improved seedsetting may be genetical in origin or it may result from more even heading and flowering; it is worth noting that the best yielding clones had short heads. The production of many germinating seeds per head must be accompanied by a large number of heads, emerging over a short period. To this end, basis clones must have a uniform heading date, as well as the potential of forming numerous heads in seed production.

The close correlation between vigour, earliness and seed yield observed in this study makes it possible to combine improved seed and herbage productivity. A more vigorous variety, even if early heading and potentially high in head number, would provide more quality grazings per year. Vigorous, late heading plants do occur in small numbers (VII, F1) and varieties could be based on them. They are, however, unlikely to have the same seed yield potential as early heading varieties. Work is in progress to examine the relationships between vigour, yield and nutritive value in more detail with due respect to physiological and morphological characteristics.

Tropical grasses have the reputation of being very stemmy and this property is often used to explain the reportedly low nutritive value of these grasses. Admittedly, in old, unfertilized pastures, culms can be seen throughout the year giving the pasture a stemmy appearance but the actual numbers rarely exceed 10 heads per m^2. Abundant heading only occurs under good N dressing and does not take place until a minimum of herbage has developed, independent of daylength (VII). Even then heading is gradual, unlike the temperate grasses, and it takes at least 6 weeks after IHE before the weight of heading tillers makes up 50% of the total dry matter (II, F1; III, P27).

General conclusion

In this study, average PGS yields obtained over 4 years, 1968–1971, were over 40 kg ha^{-1} $crop^{-1}$ for Mbarara Rhodes (IV, T2; VI, T3) and 32 kg for Nandi I (VI, T3; VII, T1). The late heading varieties in these species, e.g. Pokot Rhodes and Nandi III, only produced about half as much. The best yielding variety was Coloured Guinea with an average yield of 52 kg ha^{-1} $crop^{-1}$. On an annual basis with 2 crops per year, PGS yields were highest in 1971 amounting to 110–130 kg in Nandi I, Mbarara Rhodes and Coloured Guinea.

In absolute sense and in terms of Crop Index, such yields are still low compared with temperate grasses where yields of 500–1000 kg are quite common in small-seeded species. On the basis of yields of clean seed, Crop Index was normally only 1–2% (III, T3, T4, F1; IV, T2, T4). However, a more favourable picture arises if account is taken of the low seed rates needed for the establishment of pastures of tropical grasses (1 kg PGS) in Kenya and the long productive life of seed fields (4 years or more). If these are considered, the tropical grasses compare more favourably with temperate grasses as regards the multiplication index. In good seasons this can amount to 50 per crop.

The main conclusion from the available data is that the PGS yield can be increased substantially.

In the short run this is brought about by adopting the right husbandry techniques of adequate (+100%; III, IV) and timely (+100%; V) top dressing with N, fairly narrow row width in tufted grasses (+30%; III) and correct choice of harvesting time (+20%; VI); the increases in yield over the traditional practices are indicated by the percentages between brackets. Phosphate and seed rate were of little importance.

N is no doubt the most crucial agronomic factor. It displayed a strong interaction with row width in Nandi. High yields can only be achieved with a combination of narrow row width and high nitrogen, applied early. The present seed/nitrogen price ratio enables the grower to adopt this practice readily. One kg PGS pays for 20 kg N. Analysis of seed yield components revealed that this combination promoted rapid tillering and, subsequently, more abundant as well as more concentrated heading. The principal effect of N is to increase the percentage of heading tillers and consequently the number of heads, while narrow row width promotes the seed setting within heads. Greatly reduced seedsetting per head resulted from late N application and unfavourable weather.

It was remarkable that none of the factors, except perhaps late harvesting, had much effect on 1000-grain weight of the harvested seed. Likewise, genotypic differences, though present, were not great. Hence, improvements in seed yield must come from increases in head number and seed setting.

Although improved agronomic techniques are instrumental in raising the seed yield of a given variety, a large gap still remains in relation to potential yields which can only be overcome to any appreciable extent by breeding. With the present data at hand it is tempting to suggest that a real break-through may be achieved by selecting plants with closely matched heading date, high head number and good seedsetting, all of which displayed a high heritability.

Concern that increased head number would necessarily diminish the nutritive value does not seem justified, in view of the evidence available (VII). To the contrary, as head number and earliness of heading date are closely and positively correlated with plant vigour, more vigorous varieties would permit the farmer to graze more frequently at a high level of nutritive value. Fears that increasing the percentage of heading tillers will lower the persistence were proven unfounded by the observation that, of the present Kitale varieties, Nandi I and Mbarara Rhodes were more persistent than their late and sparsely heading counterparts.

From the genetical point of view little can be done about the prolonged intra-plant heading patterns of tropical grasses. In the tropics, even heading is found in cereal crops, which are annuals and only produce a few tillers per seedling: the plants die after reproduction. A perennial grass perennates through tillering. Thus the perennial habit and prolonged heading patterns are closely tied up with each other. Unless, of course, one succeeds in developing varieties that are sensitive to the small variations in daylength occurring near the Equator. Even if this were feasible, it may be disadvantageous in other respects.

Doubling the head number may lead to doubled seed yields but the principal gains in seed yield will come from the breeding for better seedsetting. Selection for seed retention is another important undertaking but the issue is as yet somewhat obscure. There was evidence that much of the early shedding in a seed crop consists of empty spikelets (VI). On the other hand, selection for genuine seed retention can only be based on selected plants uniform in heading date and, possibly, flowering.

An interesting finding was that the present Kitale species and varieties responded similarly towards agronomic techniques and breeding, differences being largely of a quantitative nature. This makes it justifiable, though with due caution, to extrapolate from one situation to the other.

Summary

In Kenya, successful varieties have been developed from grass species such as *Chloris gayana* (Rhodes grass), *Setaria sphacelata* (setaria) and *Panicum spp.* (Guinea grasses). However, the low seed yields and consequently high seed prices are the main barrier to a more widespread use of these varieties. Nevertheless, there has been a steady increase in the area under certified seed production from 100 ha in 1961 to 1400 ha in 1970.

The maximum yield recorded in this study amounted to 127 kg PGS (Pure Germinating Seed) ha^{-1} $year^{-1}$ obtained over 2 consecutive crops in *Setaria sphacelata* cv. Nandi I. Potential yields, calculated on the basis of seed yield components, approach those of temperate grasses, but actual commercial yields are only 5% of these. The main reason is that the seed yield components do not operate simultaneously. Within plants, heading continues for some 3 months and flowering within heads takes weeks to be completed. At seed harvest shedding and flowering often occur simultaneously within heads. Consequently, only a fraction of potentially productive heads and spikelets contributes to the PGS yield. Additionally, head numbers, seed set per head and 1000-grain weight are genetically low.

In the present varieties PGS yields can be increased substantially over former practice by:
- increasing the rate of nitrogen fertilizer to 100 kg N ha^{-1} $crop^{-1}$ (100% increase in yield over the 60 kg N used in commercial practice);
- applying N as soon as possible after the onset of the rains (100% increase over a delay of 4 weeks);
- narrowing row width to 30–50 cm for tufted grasses such as Nandi (30% increase in yield over the traditional 90 cm row width);
- delaying harvest until 10–30% of the spikelets have shed.

It was found that species and varieties responded in a markedly similar way to agronomic measures. Nitrogen rate increased the number of heading tillers. Narrow row width occasionally did the same, albeit to a lesser extent, but the principal effect of narrow row width was to increase the seed setting per head. It is thought that this was brought about by the more concentrated head emergence observed at narrow row width and better seed maturation in the short heads invariably found at narrow row width, also in Rhodes grass. Seed setting was also the principal seed yield component enhanced by early applied nitrogen. The importance of seed setting is further emphasized by the finding that PGS yields varied greatly from season to season, independently of variation in head number, while herbage yields varied little. Although seed harvesting should be delayed until at least 10–30% of the spikelets have shed, harvesting time was not found to be very critical. It could generally be spread over 1–2 weeks without reduction in seed yield. Phosphate and seed rate were observed to exert only minor effects. In contrast with PGS yields, yields of herbage dry matter at seed harvest were very high. In Nandi, 10 tons of dry matter per ha were often achieved and an average response of 65 kg dry matter was obtained per kg nitrogen applied.

Although a substantial increase in PGS yield can be achieved through agronomic techniques, considerable inter-varietal and intra-varietal variation was noticed as regards PGS

yield. Early heading varieties yielded almost twice as much as late heading varieties of the same species. In spaced-plant populations of these varieties, wide variation was noted in heading date, plant vigour and habit, and head number. There was a period of at least 4 weeks between dates of the first 5% and the last 5% of the plants to come into head. Early heading plants consisted largely of very vigorous plants with many heads. Plants of poor vigour headed late and produced few heads. In a number of selected clones, three were found to produce PGS yields on average three times as high as the group average. High heritability was observed for week of heading, PGS yield and its components. By seeking a combination of even heading date, potentially high head number, good seedsetting and high vigour, it is possible to produce varieties with improved seed and herbage productivity.

Samenvatting (Over de zaadteelt van tropische grassen in Kenya)

Kenya beschikt over een aantal goede grasvariëteiten ontwikkeld uit soorten zoals *Chloris gayana* (Rhodes gras), *Setaria sphacelata* (setaria) en *Panicum spp.* (Guinea gras), maar de zaadopbrengst is laag. Zaadprijzen zijn dientengevolge hoog en dit belemmert de inzaai op grote schaal van deze grassen. Toch was er een toename in areaal van gekeurd graszaad van 100 ha in 1961 tot 1400 ha in 1970.

De hoogste opbrengst aan PGS (kiemkrachtig zaad), die in deze studie werd behaald, bedroeg 127 kg ha^{-1} $jaar^{-1}$, verdeeld over twee oogsten in *Setaria sphacelata* cv. Nandi I. De potentiële opbrengst, berekend op basis van zaadopbrengstcomponenten, benadert weliswaar de opbrengst verkregen met gematigde grassen, doch de praktijkopbrengsten bedragen in vergelijking niet meer dan 5%. De voornaamste oorzaak hiervan is het feit dat de opbrengstcomponenten niet synchroon fungeren. Binnen een plant duurt het ongeveer drie maanden voor de meeste pluimen zijn doorgeschoten en de bloei binnen pluimen voltrekt zich over enkele weken. Het is niet ongewoon om op de dag van oogsten zowel uitval als bloei aan te treffen binnen dezelfde pluim. Derhalve draagt slechts een gedeelte van de potentieel productieve pluimen en bloempakjes bij tot de zaadopbrengst. Bovendien zijn de halmproduktie, zaadzetting binnen pluimen en het 1000-korrelgewicht genetisch beperkt.

De praktijkopbrengst van bestaande variëteiten kan belangrijk worden verhoogd door:
- het verhogen van de stikstofgift tot 100 kg N ha^{-1} $gewas^{-1}$ (100% opbrengststijging vergeleken met de gebruikelijke praktijkgift van 60 kg);
- het toepassen van de stikstofbemesting zo vroeg mogelijk aan het begin van het regenseizoen (100% opbrengststijging vergeleken met een uitstel van 4 weken);
- het vernauwen van de rijafstand in polvormende grassen zoals Nandi tot 30-50 cm (30% opbrengststijging vergeleken met de aloude rijafstand van 90 cm);
- het uitstellen van de oogstdatum tot een tijdstip waarop 10-30% van de bloempakjes zijn uitgevallen.

De verschillende soorten en variëteiten vertoonden een opmerkelijke overeenkomst in hun reaktie op teeltmaatregelen. Het effect van stikstof bestond vooral in het doen toenemen van het aantal doorschietende spruiten. Nauwe rijafstand had weliswaar soms hetzelfde tot gevolg, maar verbeterde voornamelijk de zaadzetting per pluim. Dit werd vermoedelijk veroorzaakt door een meer synchroon doorschieten van pluimen bij nauwe rijafstand en de waarschijnlijk meer gelijke rijping in de belangrijk kortere pluimen voorkomend bij deze rijafstand. De positieve invloed van een vroege toepassing van stikstof werd ook voornamelijk teweeg gebracht door een verbeterde zaadzetting. Het belang van de zaadzetting wordt voorts bekrachtigd door de waarneming dat PGS opbrengsten sterk varieerden van seizoen tot seizoen, grotendeels onafhankelijk van de variatie in pluimaantal, terwijl de opbrengsten aan totale droge stof weinig varieerden. Ofschoon de datum van zaadoogst niet dient plaats te vinden voordat 10–30% van de bloempakjes zijn uitgevallen, was de oogsttijd toch niet scherp bepaald, maar kon zonder opbrengstderving worden uitgespreid over 1–2 weken. Fosfaatbemesting en zaaizaadhoeveelheid bleken slechts van gering belang te zijn.

In tegenstelling tot de lage PGS opbrengsten werden hoge opbrengsten bereikt aan totale droge stof. Deze bedroegen vaak 10 ton op het moment van de zaadoogst in Nandi, hetgeen neerkwam op een gemiddelde van 65 kg droge stof verkregen per kg stikstof.

Teeltmaatregelen leidden tot een belangrijke opbrengstverhoging, maar er was met name ook een aanzienlijke variatie in opbrengstvermogen tussen en binnen de variëteiten. Vroeg doorschietende variëteiten brachten bijna twee keer zoveel zaad op als de laat doorschietende van dezelfde soort. Binnen de variëteiten is een grote verscheidenheid aanwezig ten aanzien van schietdatum, groeikracht, plant habitus en pluimaantal. In alle onderzochte variëteiten van Rhodes gras en setaria bedroeg de periode tussen het doorschieten van de vroegste en laatste 5% van de planten tenminste 4 weken. Vroege planten bezaten als regel een goede groeikracht en vertoonden veel pluimen. Planten met slechte groeikracht daarentegen waren laat met doorschieten en brachten weinig pluimen voort. Een aantal goede klonen werd geselecteerd waarin werd waargenomen dat een drietal topklonen gemiddeld driemaal zo hoge PGS opbrengst bezat als alle klonen gemiddeld. Een hoge heritability werd gevonden voor tijdstip van doorschieten, PGS opbrengst en de opbrengstcomponenten, met name ook de zaadzetting. Door het baseren van rassen op klonen met een gelijke schietdatum, potentieel hoog pluimaantal, hoge zaadzetting en hoge groeikracht, zal het mogelijk zijn zowel de zaadopbrengst als de weideproduktiviteit te verhogen.

Curriculum vitae

De schrijver, geboren op 4 maart 1940 te Oud-Vossemeer, ontving de gymnasium-α opleiding in Nijmegen en Bergen op Zoom. Hij begon zijn studies aan de Landbouwhogeschool in Wageningen in 1958 en behaalde in 1966 het ingenieursdiploma in de richting Plantenziektenkunde. In ditzelfde jaar werd hij door de Direktie Internationale Technische Hulp van het Ministerie van Buitenlandse Zaken uitgezonden naar Kenya en als onderzoeker verbonden aan het National Agricultural Research Station in Kitale. Sinds 1971 is hij aldaar leider van een door Kenya en Nederland gefinancierd grasveredelingsprojekt.

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Experimental studies on seed production of tropical grasses in Kenya. 1. General introduction and analysis of problems

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Summary

The development of grass seed production in Kenya is described. A discussion is given of the problems in seed growing, of which the most pressing are the low yield and quality of the seed. Low yields and quality are due to:

— prolonged head emergence within plants;
— prolonged flowering within heads;
— decreased duration of flowering in late emerged heads;
— low seed setting;
— low number of head producing tillers;
— extended spread in heading time between plants in a variety;
— other factors including low seed retention, spikelet diseases and bird damage.

All cultivated varieties show a varying combination of these factors.

Some results, together with ways of improvement through agronomic techniques and breeding, are presented and discussed.

Introduction

In recent years, many tropical countries have made increased efforts to raise livestock productivity through improved grazing. Depending upon the previous level attained, as well as upon economic incentives, the spectrum of ways of improvement may range from simple controlled herding to sophisticated practices of sown pastures receiving nitrogen dressing and supplementary irrigation. In farming systems where little progress can be accomplished by further exploitation of the available natural grazing and where a minimum level of efficient grassland and livestock husbandry has been achieved, attention will primarily be focussed on artificial pastures, planted to productive grass varieties.

The planting of a pasture obviously necessitates the supply of planting material which can be either vegetative plant parts or seed. A number of tropical grasses have, thus far, only been propagated vegetatively from splits, stem cuttings, stolons or rhizomes. Of these grasses, *Pennisetum purpureum, Pennisetum clandestinum, Digitaria decumbens* and *Cynodon* spp. are in widespread use throughout the tropical world. These species combine poor seeding properties with excellent ability for vegetative reproduction, either because they cover the ground quickly through creeping or merely due to the size an individual tufted plant may reach in a short time. Occasionally, certain grasses which could be grown from seed, are propagated vegetatively if seed is scarce or considered expensive. Unless various operations are mechanized, as in the southern parts of the USA where large areas are planted annually to *Cynodon dactylon* (Burton, 1966), vegetative propagation is very labour- intensive. Its success depends further on weather conditions after planting. A dry spell kills vegetative material quicker than seed (Bogdan, 1965b).

In general, preference is attached to the use of seed when available and, in fact, efforts are being directed towards developing seeding varieties of species hitherto propagated only vegetatively, such as *Cynodon* spp. (Burton, 1966; Bogdan, 1966). Work is in progress in Australia on the development of a seeding variety of *Pennisetum clandestinum* (Wilson, 1970).

In Kenya, only *Pennisetum purpureum* is propagated vegetatively on a large scale. It differs from normal pasture grasses in that it forms large tufts which are planted in wide rows, sometimes up to 3 m or more. Such plantings are drought-tolerant and have gained popularity for grazing in the dry season.

The development of grass seed production

For normal pastures only varieties which can produce economic amounts of seed have become popular in Kenya. Their profitable inclusion in farm rotation became apparent before the last world war in the major large-scale cereal growing areas where livestock production proved feasible. The main objective is to have a resting period with productive grass varieties for livestock, instead of the ordinary tumble-down pastures. After three to four years the pasture, normally referred to as ley, is ploughed out and planted to crops. Varietal use as governed by various climatic conditions in Kenya has been discussed by Bogdan (1960). Over 80% of Kenva receives insufficient rainfall for sustained crop production (FAO, 1969). The following only applies to those areas with adequate rainfall situated at the medium and higher altitudes, normally referred to as 'high potential' areas.

At high altitudes, above 2250 m, where year round mean monthly temperatures are lower than those of summer in the south of U.K. (Bogdan, 1960), species such as *Lolium perenne* and *Dactylis glomerata* are used extensively. Seed has to be imported as local yields are low due to limited heading in the absence of specific daylength and cold winter (Birch, 1958). At medium altitudes, however, only local tropical varieties are used. Before the advent of selected varieties in the mid fifties it was common among farmers to harvest seed of natural, dominant stands of *Chloris gayana* and *Melinis minutiflora* for farm use or sale. Names such as Rongai or Endebess Rhodes were used according to the area of origin.

With the opening of the Grassland Research Station, since 1963 incorporated in the National Agricultural Research Station, at Kitale, a serious attempt was initiated to explore the wealth of genetic material available in Eastern Africa, known to be the centre of origin of most tropical grass species. Over 4000 introductions, out of the local flora, were screened by A. V. Bogdan and R. Strange, out of which the best 9 varieties are at present under commercial seed multiplication (Table 1). Their breeding behaviour and botanical characteristics have been described by Bogdan (1959a; 1965a).

The Agricultural Census of 1960 estimated that the area under grass leys was about 80,000 ha and since then a considerable increase has undoubtedly taken place. However, reliable and up to date figures are available only for the Trans Nzoia District,

Table 1. Names and mode of reproduction of varieties grown from seed in Kenya, together with area under seed production in 1970.

Name	Mode of reproduction	Area in 1970 (ha)
Setaria sphacelata cv. 'Nandi I'	C	200
Setaria sphacelata cv. 'Nandi II'	C	200
Chloris gayana cv. 'Mbarara'	C	250
Chloris gayana cv. 'Masaba'	C	100
Chloris gayana cv. 'Pokot'	C	500
Panicum coloratum cv. 'Solai'	C (?)	100
Panicum maximum cv. 'Makueni'	A	20
Brachiaria ruziziensis	A (?)	5
Melinis minutiflora cv. 'Kitale'	A (?)	5
		1380

C = cross-pollinating; A = apomictic.

of which Kitale is the centre. A survey held in this district has shown that 9.4% of all available grazing was under planted leys, involving some 17,500 ha. Trans Nzoia District comprises only about 5% of the high-potential areas of Kenya, leading one to suggest that an overall area of 350,000 ha could be expected assuming an equal proportion of leys in the other districts. The latter is certainly not correct as figures of seed sales indicate that one third of all grass seed offered for sale is sold to farmers in the Trans Nzoia District.

As mentioned above, grass seed production in Kenya started off with the harvesting of seed from natural stands. With the advent of selected varieties, initial bulking remained in Government hands for some years. In 1956 the Kenya Seed Company was set up at Kitale by grass seed growers, and this gave a strong impetus to the production, processing and marketing of seeds of selected varieties. The expansion in the area under grass seed production in the last 10 years is shown in Table 2.

This increase in area obviously mirrors the increase in demand which, as yet, has exceeded the supply of seed. It is of particular interest to note that the small farmers are increasingly becoming aware of the profitability of sown pastures. Not only Kenya is developing its livestock industry, but so are many other tropical countries. Considerable quantities of seed, particularly of *Chloris gayana* and *Setaria sphacelata*, have been exported to Australia, Japan and neighbouring countries like Uganda and Tanzania. The outstanding performance of Kitale varieties has also been shown in countries as different as Madagascar, Cameroon and Guyana (Borget, 1969). No other

Table 2. The increase in area under grass seed production.

Year	Area (ha)
1961	100
1962	200
1966	500
1967	600
1968	700
1969	800
1970	1400

country has yet been engaged in production for exporting tropical grass seed so that the prospects are bright for Kenya.

Current seed growing practices

Since most of the seed is produced on mixed farms where maize and livestock production are the two major undertakings, grass seed production was decidedly a sideline in the early years and was seldom regarded as an integral part of the farming system. Cereal prices were high in contrast to the relatively low economic return from grass seed growing and at that time growers had not much experience of techniques. In addition, as livestock production was a major part of the farming system, a grower would close up a pasture for taking a seed crop only if grazing was not limited on the farm. However, maize prices have gone down by about 33% since 1965 and are expected to remain at this level for some time. Equally important is that growers have obtained more experience in handling the grass seed crop. As a result, nearly every grower will now make an effort to obtain at least one seed crop a year and many of them will aim at a second crop by the end of the season. Even then, an appreciable amount of grazing is still left in the aftermath herbage.

To explain this system of multi-cropping it is important to look at the climatic conditions of the Kitale area where most of the seed is grown. Kitale (1° N) is situated at nearly 1900 m altitude. Mean monthly temperatures are on average 19.1° C in February, 19.4° C in March and 19.3° C in April, which are the warmest months. In the coolest months these temperatures are 17.2 and 17.3° C for July and August (Woodhead, 1968). Maximum day temperatures are seldom above 30° C and minimum night temperatures are rarely below 9° C. The variation in daily temperatures is, therefore, much greater than between months. Near the Equator solar daylength is about 12 hours. At 1° N solar daylength only varies by 9 minutes over the year. The rainy season usually starts in late March and continues until late November, with most of the rain being received between March and September. December till March is normally dry. Average annual rainfall is nearly 1200 mm.

With this type of climate it is feasible to obtain 2 full seed crops a year. Following sowing in early April, the first seed crop will be ready in August or September and a light second crop can be reaped from the aftermath by the end of the season. In the second and subsequent years, following a cleaning cut and topdressing with nitrogenous fertilizer at the onset of the rains, a first crop can be harvested in June or July and a second full crop in October or November.

Up till now, seed growing practices have been rather haphazard. Most species, whether stoloniferous or tufted, were given a similar treatment. The standard drill width is 90 cm. This is largely determined by the customary width of maize implements rather than by a proven superiority of any given width of drill. This row width became popular at a time when mechanical cultivation was regarded as indispensable for weed control and for supposed soil-improving purposes. The standard seeding rate is the equivalent of 1 kg/ha of Pure Germinating Seed (P.G.S.). Phosphate fertilizer at a rate of 50 kg P_2O_5 is normally mixed with the seed prior to planting. Both hand and machine planting are practiced. Shallow planting is essential (Bogdan, 1964) and rolling favours rapid germination. Normally, various combinations of mechanical cultivation, hand weeding and herbicides, mainly 2,4-D, are used for weed control. If weed control is inadequate no seed harvest is taken until the crop itself has grown away from annual weeds with the aid of the grazing cow and a rotary slasher. The latter practice means a loss, however, since the first year crop yields well, with little or, normally, no nitrogenous fertilizer. In the second and subsequent years topdressing with 60 kg N per ha is carried out at the beginning of each growth cycle, although economic returns have been obtained from over 100 kg N per ha. Higher rates of N also result in more aftermath herbage for grazing.

Determining the right stage for seed harvesting is difficult. Most growers decide to delay harvesting until part of the seed has shed, which is normally 7 or 8 weeks after initial head emergence. Harvesting is either carried out with a reaper binder, if labour is scarce, or by hand with sickles. Heads are cut off above the leaf canopy, bound and stooked in the field. Some two weeks later stooks are collected and threshed, normally by beating the seed out with sticks on a sheet. Rough particles are sieved out and the seed is dried in the sun before being taken to the seed firm for cleaning and processing.

Burning seed fields after grazing is practiced at the end of the dry season to get rid of excess foliage. It certainly is also a hygienic practice to destroy crop debris harbouring diseases and pests.

Seed fields can economically be maintained in a productive stage for at least four years, if kept reasonably free from perennial grass weeds.

A new certification scheme covering all important seed crops has been initiated in 1969. Legislation and rules are in compliance with those of OECD. Under this scheme, basic seed denoting breeder's seed as well as elite seed will be produced under the supervision of the breeder, for the production of certified seed on growers' farms.

Another promising development in the grass seed industry has been the setting up of a seed growers association. Once established fully, it will provide a useful medium for contacts with seed firms and government institutions.

Problems in grass seed growing

The most pressing problems are of a crop-physiological and genetical nature; these will be discussed later. At this stage, however, some of the technical problems in the above practices need to be mentioned.

Mechanization of harvesting and weed control, the overriding subjects of research on grass seed production in temperate countries, do not require urgent attention in Kenya as long as hand labour remains the most practical, economic and least weather-dependent way of handling a seed crop. In fact, labour-intensive methods are to be preferred in countries faced with acute unemployment problems. With maximum use of hand labour 15–20 man-days are required per hectare for all operations between the cutting of heads and delivery of uncleaned seed to the seed firm. At the present wage level, costs of hand labour would still be only 30–50 % of the costs of mechanized combine-harvesting, even if this were at all feasible. In fact, preliminary trials with combine-harvesters have shown discouraging results. Seed is of inferior viability and there are very great problems with the first crop which matures in the wettest months. Worst of all, a good seed crop is mounted on some 8–10 tons of herbage dry matter, which is decidedly difficult to pass through a combine, even when allowed to dry in wind-rows after mowing. Unless heads are cut under dry conditions, seeds will shatter readily on the ground if not protected in well covered stooks. As a compromise, reaper binders are used extensively in peak periods when labour is scarce.

As far as weed control is concerned, 2,4-D herbicides are economically applied against a wide range of broad-leaved weeds, but hand weeding is the most effective method against obnoxious annual and perennial grass weeds. Problems of seed cleaning are under investigation (Oomen, 1969). Storage and seed longevity pose relatively few practical difficulties since most grass species do not reach maximum seed maturity until six months after harvesting, and most of them retain this for over two years (Moore, 1962). In the warm and humid tropics at low altitudes, however, grass seed longevity is a major limiting factor (Behaeghe, 1960).

Given adequate rainfall and nitrogen supply, seed crops of *Setaria sphacelata* and *Chloris gayana* will mature within 3–5 months after the cleaning cut. Provided the first crop is allowed to commence growth at the onset of the rains, 2 crops can be obtained, while still allowing sufficient time to utilize the herbage after the first seed harvest. This herbage can amount to 6–8 ton per ha of dry matter, with a crude protein percentage as high as 7% (Dougall, unpublished data). Most growers regard the utilization of this good quality herbage left after the seed crop as being an essential part of the whole enterprise. After the second seed crop, coinciding with the onset of the dry season, direct grazing is the most economic method even though losses due to trampling and fouling are considerable. After the first seed crop, however, when rainfall is normally high, such utilization through direct grazing is less urgent on account of the abundant grazing then available in the actual pastures on the farm. Grazing may take a considerable period and leave insufficient time for a complete growth cycle of the second crop, particularly if the first seed crop is already late. A better proposition would be to conserve this herbage as silage for feeding during the dry season, when the supply of cheap fodder is limited on most farms. Whether grazing or ensiling is practiced, either of the two is better than merely slashing the herbage, leaving it in the field and topdressing with nitrogen over it. Apart from the loss of quality fodder, regrowth is seriously hampered by the thick layer of slashed grass on the ground and it can safely be assumed that nitrogen is withdrawn to make the slashed herbage decompose.

The most pressing problems are presented by the low seed yields and the low percentage of Pure Germinating Seeds (P.G.S.) normally encountered. Present annual seed yields in commercial fields rarely exceed 200 kg/ha while a P.G.S. percentage of 25 is considered good. Consequently, effective annual seed yields of more than 50 kg P.G.S. per ha are exceptional. This compares very unfavourably with seed yields of grass species in temperate climates, where effective seed yields of over 1000 kg/ha are common in many varieties. On the other hand, 1 kg P.G.S. is adequate to establish 1 hectare of pasture (Strange, 1957), pointing to a multiplication factor of 50.

Table 3. Costs of seed for the establishment of 1 ha in 1970.

	Seed rate (kg P.G.S.)	Costs (Kshs)[1]	Seed costs as a percentage of total establishment costs
Ley of tropical grass	1	100	20
Ley of temperate grass	4	25	5
Hybrid maize	20	50	7
Sunflower	7	20	3

[1] 1 Ksh. = 1 Kenya shilling = US $ 0.14.

But even then, the seed costs for establishing one hectare of a tropical grass still compare unfavourably with the costs incurred when planting pastures with imported seed of the temperate grasses used at high altitudes in Kenya, as mentioned above. A comparison of seed costs is given in Table 3, including also the seed costs of two common annual crops.

Although the seed costs are depreciated over a number of years, it is evident that the high cash expenditure deters many farmers who are not familiar with the ultimate profitability of sown leys. Consequently, the use of selected, productive varieties remains below the potential, which, in turn, restricts demand and expansion in seed production area. This vicious circle can most effectively be broken by finding out how to make a substantial increase in effective seed yields per hectare.

Causes of low seed yield (literature review)

Surprisingly little experimental work has been conducted on field problems of seed production in tropical grasses, although a considerable amount of chiefly cytogenetical research work has been carried out on some grasses normally propagated vegetatively, such as *Digitaria decumbens, Pennisetum clandestinum, Setaria splendida, Pennisetum purpureum* and *Cynodon* spp.

The Pangolagrass variety of *Digitaria decumbens,* widely used in the southern USA and the Caribbean, is a sterile interspecific hybrid, producing numerous flowering heads but no viable seed (Sheth et al., 1956). Both male and female sterility were found to cause this. Male sterility is also encountered in *Pennisetum clandestinum* either due to low temperatures (Youngner, 1961) or to cytological irregularities (Hrishi, 1952). Carr and Eng Kok Ng (1956) observed an increase in flowering following severe defoliation. This is commonly observed in Kenya on lawns planted to this grass.

Setaria splendida displays a high degree of pentaploidy and heptaploidy which apparently causes the very low yields of viable seed normally obtained (Hacker, 1966).

In *Pennisetum purpureum,* only few varieties produce heads in Kenya but never abundantly. This species has been crossed in a number of countries with *Pennisetum typhoides,* a cereal, to produce hybrids possessing amongst other qualities better seeding properties.

Kenya varieties of *Cynodon* spp., known as star grass, produce few flowering heads and little seed, necessitating vegetative propagation. Attempts have been made to develop a seeding variety (Bogdan, 1966) but progress is hampered by the occurrence of *Claviceps* and *Ustilago* spp. affecting the spikelets. *Cynodon dactylon* var. *dactylon,* known as Bermuda grass, has been the subject of intensive breeding work in the USA (Harlan, 1970). Many hybrids were developed for vegetative propagation. Over 2.5 million hectares are planted to Coastal Bermuda grass. A need is, however, felt to develop seeding varieties (Burton, 1966).

It has been mentioned above that these species combine poor seeding properties with excellent suitability for vegetative propagation. They are, invariably, highly productive varieties in many parts of the world. The ease of vegetative reproduction has been of great adaptive significance in the absence of an adequate mechanism for generative reproduction.

Returning to the seed-multiplied grasses, it is now important to discuss some theories that are sometimes adduced. Very little field experimentation has been conducted, and this has led to some generalized statements to explain the poor seeding properties of tropical grasses. It has been said that most tropical grass species belong to tribes having an inherently low potential for seed yield. These tribes are the Paniceae and the Andropogoneae. Among these, however, some important cereals have evolved such as *Panicum miliaceum, Setaria italica, Pennisetum typhoides* and *Sorghum vulgare*.

Another suggestion is that tropical grasses have been subject to little or no domestication for seed production. In comparison with cereals this is certainly true. However a considerable number of good seeding varieties of temperate grass species originate from the wild flora in much the same way as varieties of tropical grasses.

It has also been suggested that apomixis which is unusually common in the Paniceae and Andropogoneae, is associated with poor seeding properties (Bogdan, 1959a). Warmke (1954) reporting on a cytological study suggests that the low seed yielding ability of *Panicum maximum*, a facultative apomict, is due to degeneration of all four reduced megaspores, without apospory, and due to occurrence of more than one embryosac within an individual ovule. *Panicum maximum* is certainly the poorest seeder of all commercial species in Kenya. Seed yields, however, of *Melinis minutiflora*, probably also an apomict, are comparable with those of the best cross-pollnating species. Also seed yields of the temperate apomict. *Poa pratensis*, can be very high (Evers and Wolfert, 1959). In general, apomixis is considered to be of great adaptive significance to overcome cytogenetical barriers. On the other hand, it can be seen from Table 1 that the seed production area under apomictic species is only very small.

Little or no seed is often obtained from single-clone plantings owing to self-incompatibility. Where vegetative propagation is practiced on a commercial scale, plants often derive from one single superior genotype.

Reviewing the above literature is appears necessary to study the main factors affecting seed yield under field conditions from the beginning. It is especially important to study the various aspects of flowering which is generally known to be extended.

An analysis of factors affecting seed yield

Crop physiological studies carried out by the author since 1966 have shown that seed yield and P.G.S. percentage are low due to seven main reasons.

1 *Prolonged head emergence within plants*. Individual plants of tropical grasses show head emergence over a period of up to 3 months or longer. Even under crop conditions this was found to result in the following generalized patterns of head emergence (Fig. 1).

Varieties differ as to the degree of concentration in head emergence and this is immediately reflected in the seed yields. *Panicum coloratum* heads rapidly and is a very good seeder. *Panicum maximum*, however, heads almost continuously and is, therefore, a poor seeder. Peak emergence, i.e. the stage when most heads emerge per week, is normally around the 6th week. Initial head emergence is here defined as the stage when 5 to 10 heads have emerged per m².

It is evident that this pattern of head emergence in tropical grasses is in sharp contrast to that of cereals in general and of grasses in temperate countries in which heading is concentrated in a very short period, often only a matter of a few days. Experience has also shown that tropical grass varieties commence heading and produce

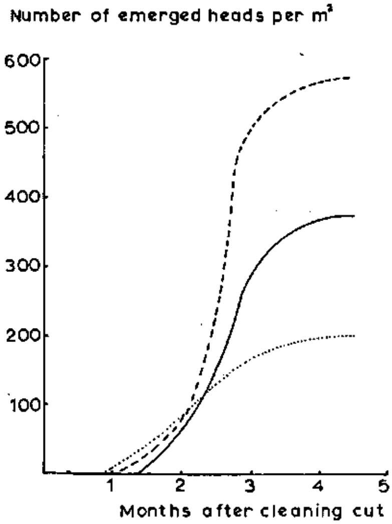

Fig. 1. Schematic representation of head emergence in crops of three cultivated species of tropical grasses. — — — *Panicum coloratum* cv. 'Solai'; ——— *Setaria sphacelata* cv. 'Nandi I'; .... *Panicum maximum* cv. 'Makueni'.

a good seed crop at any time of the year provided rainfall and nitrogen supply are not limiting. Under such conditions heading will commence 3–10 weeks after the cleaning cut. The length of this pre-heading period depends on variety, age of the crop since planting, stage of growth at which the last preceding crop was cut, and on weather conditions. Cold weather appears to prolong the pre-heading period. Heading is also delayed by burning the immediately preceding crop.

Reviewing the sparse literature on daylength responses in tropical grasses Evans (1964) suggests that the small seasonal changes in tropical daylengths may have marked effects on inflorescence initiation, as in several rice and sugar-cane varieties.

However no evidence exists to suggest that the solar daylength variations of some 9 minutes at Kitale have a visible effect on heading in Kitale varieties. Head initiation might be different at other latitudes. However even in Israel and the southern parts of the USA, both north of 30° N, more than two seed crops can be taken of *Chloris gayana* per year, obviously in different seasons with different daylength regimes (Gordin-Sharir, 1966; Wheeler, 1950).

It has been mentioned already that Kitale varieties are grown in many countries, even beyond the tropics of Cancer and Capricorn. Very few data are available on seed yield and % P.G.S. of Kitale varieties at other latitudes, but, even then, it would not be justifiable to ascribe higher or lower yields solely to differences in daylength.

The impact of prolonged heading on seed yield has been discussed by Boonman (1967). Since seeds usually begin shedding within 4–5 weeks after the particular head has emerged, a loss of seed is incurred, no matter when the crop is harvested, due to shedding in early emerged heads and incomplete seed formation in late emerged heads, while a proportion of heads is still enclosed in the leaf sheath. Determining the optimum time of harvesting, i.e. the time at which the highest amount of completely formed seed can be harvested is, therefore, of utmost importance.

2 *Prolonged anthesis and stigma exsertion within single heads.* In *Setaria sphacelata* anthesis and stigma exsertion, i.e. the actual flowering, were found to continue for 7 weeks (Table 4). It is indeed quite common in varieties of this species to find

Table 4. Duration of flowering and mean head length in successive weekly age-groups of head emergence in a seed crop of *Setaria sphacelata* cv. 'Nandi II'.

	Age-group of head emergence (weeks)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Duration of flowering (weeks)	7	7	5	2	2	2	1	0	1	0	0	0	2	2
Mean head length (cm)	18	17	19	19	19	19	19	18	18	17	16	13	13	13

abundant flowering, even in the early emerged heads, on the optimum date of harvesting, normally some 6 weeks after initial head emergence. Consequently, it is not uncommon to find shedding and flowering within the same head. The ear-like panicles of *Setaria sphacelata* are relatively long (Table 4). In the digitate panicles of *Chloris gayana* cv. 'Mbarara', individual racemes are rarely longer than 8 cm and this may explain why anthesis within heads of this variety is completed within 3 weeks. Bogdan (1959b) found flowering within racemes in the Kerio variety of this species completed in only 2 weeks.

3 *The decreasing duration of flowering and decreasing headlength in progressively later emerging heads.* Observations were made in an area of 6 $\times$ 7.2 m of a first year's seed field planted in 90-cm rows. Heads emerging during a particular week were labelled at the end of that week with coloured chicken rings. Flowering was recorded every two days and the mean head length of every weekly age-group was determined. The observations continued for 14 weeks by which time the crop became so aged that new tillers and heads began to appear through.

It can be seen from Table 4 that the early formed heads flowered over a period of 7 weeks. Later emerged heads flowered progressively shorter and no flowering was observed after the 7th week. No evidence was found that later emerged heads flowered more intensively during their short period of flowering. Flowering appeared again with the 13th week, probably due to the opening up of the aged leaf canopy.

The mean head length decreased from 19 cm at the maximum to only 13 cm at the end. The earliest heads were somewhat shorter than those with maximum head length. This has been observed on many other occasions, also in *Chloris gayana.* In both species, overall mean head length is longest in the first year's harvest and is reduced to about 60% in subsequent years.

Although the percentage of seed setting per head could not be determined due to the technical difficulties involved, it can safely be assumed that the seed setting efficiency decreased progressively as head emergence continued (Anslow, 1963).

Also in seed crops of *Chloris gayana* a similar situation was observed. Both number of racemes per head and mean raceme length decreased at progressively later stages of heading.

The above may also explain why optimal time of seed harvesting is normally earlier than one would calculate on the basis of a head emergence curve. For seed setting is apparently better in early emerged heads than in those of peak emergence and subsequent groups.

4 *Low seed setting per head.* A head of *Setaria sphacelata* of average length (12 cm) bears 500–750 single spikelets each with one fertile floret (Gildenhuys, 1950). The

1000-grain weight of clean seed is normally around 350 mg. At maximum seed setting, i.e. when all spikelets contain viable caryopses, an average head could produce some 200 mg of Pure Germinating Seed. By simply dividing overall yield of P.G.S. by the number of heads concerned in various field experiments, the average yield of P.G.S. per head does not exceed 20 mg, thus only 10% of the potential. In view of (3) early emerged heads may produce considerably more than this and later emerged heads considerably less.

Obviously, the low average percentage of seed setting does not stand on its own, since (1), (2) and (3) are deeply involved which may mask the actual potential of individual spikelets to set seed. Also Burton (1943) reported low seed setting in a number of tropical grasses.

5 *Low number of head producing tillers.* In the course of experiments it was observed that the head number per m² in average seed crops of *Setaria sphacelata* and of *Chloris gayana* rarely exceeded 200 and 250, respectively.

Working on temperate grasses, Evans (1959) observed up to 280 heads in cocksfoot S 143, 680 in timothy S 48 and 1450 heads in perennial ryegrass S 23. Considering that the ear-like panicles of *Setaria* resemble timothy panicles in appearance and length, it becomes evident that the observed head numbers limit seed yield in tropical grasses. Concurrently, only a small proportion of the tillers formed — up to 2500 tillers per m² have been observed in *Setaria sphacelata* at stages prior to initial head emergence — produces an emerged head at harvesting time.

6 *Large variation in time of initial head emergence between plants within a variety.* Kitale grass varieties showed an unusually extended spread in time of initial head emergence and subsequent seed maturation between plants. This is well illustrated by the results given in Table 5 for *Chloris gayana* cv. 'Pokot'. 758 spaced single-plant plots of 2.5 × 2.5 m were scored weekly for initial heading which denotes first head emergence when commencing all over the plot. The field was in its third year.

A similar extended spread has also been noticed in other varieties and species. Needless to say, such a wide variation leads to a considerable loss of seed due to a correspondingly wide variation in date of maturity. The first plants are ready for harvest when the last plants just begin heading.

In addition, this wide variation implies unsatisfactory inter-plant fertilization and a greatly increased risk of genetic shift. It can be seen from Table 5 that most plants produce initial heading in the first 3–4 weeks. The chance that the first and last groups intercross is very small. The obvious consequence of this would be that successive generations will head at a progressively earlier date.

Evidence that this is actually happening in the Kitale grass varieties is illustrated in the following finding. Splits of *Setaria sphacelata* cv. 'Nandi I' were collected

Table 5. Percentage of plants showing initial heading.

	Week						
	1	2	3	4	5	6	7
Percentage of plants	4	19	19	22	16	14	6

Table 6. Head numbers at initial heading and final seed yield in clones of *Setaria sphacelata* cv. 'Nandi I', temporarily grown under varying conditions (seed field = 100).

Origin of clones	Head number at initial heading	Seed yield
Seed field	100	100
Ley D	65	89
Ley C	34	89
Ley B	26	82
Ley A	8	72

during 1967 from 4 old leys in the Kitale area and from a seed field. The old leys had been planted some 10 years earlier at the time that the first seed of this variety was released. The seed field, however, originated from the same release but had subsequently been subject to at least 5 generations of continuous seed multiplication. 100 clones of each source were interplanted. Heads were counted at the initial heading stage and the seed yield was determined (Table 6).

The occurrence of shift is quite obvious. Unfortunately, the original parental clones could not be included since they were no longer available. It is, therefore, difficult to distinguish a tendency towards earliness in the seed field clones from a tendency to lateness in the clones deriving from the old leys.

It can, however, safely be assumed that both processes have taken place concurrently. Seed harvesting was carried out at too late a date for the seed field clones so that their seed yield was relatively low.

The difference between head numbers in clones from the various leys can be explained on the basis of the management history of these leys. Intensity of management and grazing had been best in ley A and had been decreasingly less in ley B, C and D. This shows clearly that early types had been eliminated under intensive grazing of some 10 years.

The wide range in heading time, observed in the Kitale grass varieties, is the obvious result of uncontrolled, continuous seed multiplication. Parental stocks were not maintained and every new generation was established with seed from a previous one. This has necessitated renewed selection.

7 *Other indirect limiting factors including seed shattering, spikelet diseases, bird damage and ease of lodging.* Seed retention is a character which is not highly developed in the Kitale grasses. Like seed setting, seed retention does not stand on its own. Early emerged heads in early plants are bound to shatter their seed by the time the bulk of the crop is mature.

Tilletia echinosperma is a common spikelet disease in *Setaria sphacelata* and *Panicum maximum.* Occasional heavy infestations occur. Small seed eating birds are also quite a nuisance, especially in isolated small experimental fields.

The above 7 factors affect all varieties in varying combinations resulting in low yields and P.G.S. percentage. The Crop Index is very low, too. In *Setaria sphacelata,* to take one example, average annual yields of clean seed are 150 kg against a total of 15,000 kg harvested dry matter. The Crop Index is, therefore, only 1% against 10% and 50% normally found in temperate grasses and cereals, respectively.

Purely on the basis of seed yield components and irrespective of prolonged heading and flowering, a potential yield of 450 kg/ha of P.G.S. can be calculated for an average crop of *S. sphacelata* (200 heads per m² × 750 seeds per head × 0.3 mg per seed). This is 900 kg per year which approaches commercial yields in temperate grasses. Actual commercial seed yields in tropical grasses, however, are only 5% of this.

Work in progress

As a consequence of the above analysis of factors affecting seed yield, work is now in progress on field research along the following lines:

1 Given a particular pattern of heading in the field, to accomplish maximum yield of P.G.S. by determining the right harvesting time.

2 To influence the pattern of heading both by enlarging its scale and by concentrating this increased number over a shorter length of time.

Close tiller density in combination with the optimum level of nitrogenous fertilizer were found to be the major changes which attained these objectives and led to substantial increases in yield and P.G.S. percentage over traditional seed growing practices (Boonman, 1970).

3 On account of the great variation in heading time and the risk of genetic shift, all varieties listed in Table 1 have now been stabilized through the establishment of spaced-plant populations. Propagation material was obtained from present seed fields. Seed fields and not leys were chosen as source of material for the following reasons. Firstly, varietal name and history of the chosen seed fields were known with certainty. Secondly, benefit may be obtained from the natural selection, which will certainly have taken place towards better-seeding properties, rather than merely towards earliness and increased heading. Indeed, the spaced-plant populations offer useful variations in desirable characteristics, not only in head numbers but, more favourably so, also regarding concentrated heading, head length, seed setting and seed retention. On the herbage side, great variability exists as regards growth habit, vigour, leafiness and disease resistance. Seed yield rather than herbage productivity is considered to be the main factor limiting the use of Kitale grass varieties. The problems encountered when breeding for higher seed yields in herbage varieties have been discussed by Griffiths et al. (1966).

Throughout the course of field experiments, particular attention is given to patterns of tillering and head emergence and to the analysis of seed yield components. This approach was found to explain many of the problems, and also to increase the efficiency of field experiments.

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Experimental studies on seed production of tropical grasses in Kenya. 2. Tillering and heading in seed crops of eight grasses

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Summary

Tillering in seed crops grown undisturbed for six months was studied over two years in varieties of *Setaria sphacelata, Chloris gayana, Panicum coloratum, Panicum maximum* and *Brachiaria ruziziensis.* Tiller numbers rose to a maximum around the time of initial head emergence (IHE) (5–10 heads per m^2), followed by a decline and finally a levelling off. Head emergence was found to continue in some varieties for over three months. The weight per tiller increased at a linear rate. Tiller numbers never exceeded 1900 per m^2. In the year of planting, tillers were less numerous but heavier than in the subsequent year. Total dry weights of tillers were also highest in the first year.

Seed yield was significantly correlated with degree of concentrated head emergence and percentage of heading tillers in a variety. It is suggested that, within varieties, plants with heavier tillers may produce higher seed yields. Varieties within species can be identified according to date of IHE.

A type of culm branching is described whereby tillers develop into flowering culms out of elevated nodes of erect parental culms.

Introduction

In a previous paper (Boonman, 1971) various factors limiting seed yield of tropical grasses in Kenya were listed. It was indicated that prolonged heading, which may last over three months, was an important factor reducing seed yield.

The present study attempts to elucidate the heading pattern of some contrasting varieties by following the tillering behaviour under crop conditions. As shown in work with temperate grasses, knowledge of tillering is important for a better understanding of the seed crop (Ryle, 1966).

Numerous studies are available on tillering in temperate grasses, which have been reviewed by Langer (1963), Humphreys (1966a) and Dorrington Williams (1970). Reports on tillering in cultivated tropical grasses are, however, only very few (Humphreys, 1966b; Haggar, 1966; Singh and Chatterjee, 1966; Chatterjee and Singh, 1968).

Materials and methods

The following varieties were planted from seed on 9 April 1968 in adjacent plots

	Common name
Setaria sphacelata cv. 'Nandi I'	Mbarara Rhodes
Setaria sphacelata cv. 'Nandi III'	Nandi I
Chloris gayana cv. 'Mbarara'	Nandi III

Chloris gayana cv. 'Masaba'	Masaba Rhodes
Chloris gayana cv. 'Pokot'	Pokot Rhodes
Panicum coloratum cv. 'Solai'	Coloured Guinea
Panicum maximum cv. 'Makueni'	Makueni Guinea
Brachiaria ruziziensis	Congo Signal

Since the plots were more than 500 m^2 in size, they could not be laid out in a compact block on the narrow terrace reserved for this study. In the design used, the distance between any two fields did not exceed 200 m.

Seed at a rate equivalent to 1 kg per ha Pure Germinating Seed (PGS) was mixed with single superphosphate at 40 kg P_2O_5 per ha and planted in rows 75 cm apart. The number of rows of each entry in the investigation was 30, not including some guard rows at the edges. As no uniform row length could be adopted on account of the varying width of the terrace, rows were 29 m long in Nandi, 24 m in Rhodes and only 19 m in the other varieties. The fields were subdivided into replicates running across the direction of rows. Owing to the varying row length, four replicates were imposed on the fields with 19 m rows and five on those of 24 and 29 m rows. The length of row within each replicate was 3, 4 and 5 m, respectively.

During 1968, only the top replicate was used for observations on tillering, the other replicates being set aside for concurrent determinations of seed yield at various harvesting times. Only seed yields obtained at the optimum harvesting time will be reported here. In the top replicate, in each of 4 plots consisting of 4 rows, portions of undisturbed 50 cm row length were cut at weekly intervals for a period of 12 weeks. The sampling procedure involved the cutting of tillers just above ground level, separating into heading and non-heading tillers, counting, oven-drying and weighing. Sampling for tillering commenced when the first variety, *Panicum coloratum*, began heading, on 8 July, 13 weeks after planting, and was discontinued 11 weeks later on 23 September.

In 1969, another method of sampling was adopted when it was observed that the 1968 method of cutting adversely affected subsequent regrowth or even killed plants, probably due to low cutting and competition from the surrounding undisturbed crop. The cleaning cut and subsequent top dressing with 50 kg N as ammonium sulphate nitrate per ha was carried out on 9 May. The cleaning cut was meant to remove the growth that had developed after a previous cleaning cut on 21 March on which date a top dressing had been given of 40 kg P_2O_5 per ha and 50 kg N per ha. Counting of tillers began on 12 May, three days after the cleaning cut. The tiller counts were carried out weekly in situ in sections of 25 cm row length at 12 random sites over the whole field. Every week 12 new sites were taken.

After counting in situ, numerous sections of less than 5 cm row length were cut as low as possible. These samples were mixed together; loose leaves and dead material were removed and 3 samples of 100 tillers were chosen at random, oven-dried and weighed separately. On 9 June, the fifth sampling date, crop growth became too heavy and dense for further tiller counts in situ, and no alternative was left but to revert to the method used in 1968, although four extra samples were now taken in the other replicates giving a total of eight. In July and August, samples were taken once every two weeks and in September and October once every three weeks. The sampling period covered 24 weeks.

For the purpose of this experiment the total number of tillers was divided into two categories:

– heading tillers; these are tillers in which heads have fully emerged, the dividing point

Table 1. Official rainfall figures (mm) for Kitale over 1968 and 1969.

Year	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1968	1	147	69	201	95	127	176	121	60	88	57	18
1969	62	58	107	54	215	49	101	176	116	119	52	6

being when the base of the head is visibly free from the leaf sheath.

- non-heading tillers; any type of tiller that has not produced an emerged head.

Unless stated otherwise, the term tiller will hereafter refer only to the overall number unless a specification of heading or non-heading is given.

In view of the scope of this study, no attempt was made to dissect tillers for the detection of flower initiation. The above classification is therefore used instead of one which divides them into vegetative and generative, or fertile and sterile tillers.

The official rainfall figures in mm for Kitale over the two years under review are given in Table 1.

Results

Data on numbers and weights of non-heading and heading tillers were obtained in all eight varieties over 1968 and 1969. Only essential data are presented here, but the complete set can be obtained from the author upon request.

The data on time of Initial Head Emergence (IHE), maximum tiller numbers and weights are shown in Tables 2, 3, 4 and 5. In Fig. 1 the tillering patterns of three characteristic varieties in 1969 are shown. Fig. 2 presents the head emergence curves of all varieties for both years. Table 6 and Fig. 3 show the correlation between seed yield and tillering and heading characteristics. In Fig. 4 a presentation is given of the mean culm length as heading proceeds.

Time of Initial Head Emergence (IHE)

The time of IHE is defined as the time when 5–10 heads have emerged per m^2. The data of 1968 and 1969 are shown in Table 2. Also those of 1970 were added because observations on IHE were continued in that year.

Table 2. Sequence in time of initial head emergence (IHE) over weekly intervals.

Variety	1968	1969	1970
Nandi I	3	4	4
Nandi III	6	6	5
Mbarara Rhodes	2	1	3
Masaba Rhodes	3	2	6
Pokot Rhodes	5	3	7
Coloured Guinea	1	2	1
Makueni Guinea	5	1	3
Congo Signal	8	1	12

Within columns, each value indicates the week in which the particular variety showed IHE, the earliest variety bearing the value 1. No calendar dates are given because heading did not start in the same month each year due to differences in date of cleaning cut and because in the year of planting IHE is usually a few months later than in subsequent years.

Coloured Guinea was consistently among the first varieties to show IHE, followed by Mbarara Rhodes. Makueni Guinea was early in 1969 and 1970 but not in the year of planting (1968). This variety is known to be the most drought-tolerant variety in the range under review and as a result it may develop quicker after the onset of the rains; on the other hand it is known to establish slow from seed under Kitale conditions. Pokot Rhodes and Nandi III were late heading varieties. Congo Signal behaved erratically. It is further evident that Nandi I showed IHE 1–3 weeks earlier than Nandi III and that Mbarara Rhodes was earlier than Masaba and Pokot Rhodes, the latter being latest. It was not possible to discern a clear sequence among the species themselves, although Nandi appeared to be a late group.

Numbers of tillers and heads

In both years, tiller numbers rose to a maximum that coincided roughly with the time of IHE. In 1969 maximum numbers were attained within 2–6 weeks after the cleaning cut and in 1968 14–19 weeks after planting, depending on the variety.

In the year of planting, maximum numbers were often less than half of those of the subsequent year and varied from 560 per m² in Pokot Rhodes to 800 in Nandi III (Table 3). In 1969, maximum numbers varied from 1280 in Congo Signal to 1920 per m² in Nandi III. Thus Nandi III produced the highest number of tillers in both years, followed by Mbarara and Masaba Rhodes. Consequently, Nandi III produced more tillers than Nandi I, while Mbarara and Masaba Rhodes produced more than Pokot Rhodes.

In Fig. 1 tillering curves are presented for three varieties in 1969, representing three different combinations of herbage and seeding properties. Nandi III is known to be a good pasture grass, but a poor seeder. In contrast, the opposite applies to Coloured Guinea. Mbarara Rhodes, however, combines good herbage with good seeding proper-

Table 3. Numbers of tillers and heading tillers (heads).

Variety	1968				1969			
	maximum number of tillers per m²	maximum number of heading tillers per m²	%	heading tillers at final sampling (%)	maximum number of tillers per m²	maximum number of heading tillers per m²	%	heading tillers at final sampling (%)
Nandi I	620	120	19	27	1,400	350	25	57
Nandi III	800	90	11	18	1,920	170	9	19
Mbarara Rhodes	790	210	27	33	1,610	320	20	31
Masaba Rhodes	700	260	37	53	1,800	230	13	39
Pokot Rhodes	560	110	20	38	1,380	160	12	29
Coloured Guinea	610	390	64	77	1,530	520	34	76
Makueni Guinea	600	70	12	18	1,330	130	10	45
Congo Signal	690	220	32	50	1,280	470	37	78

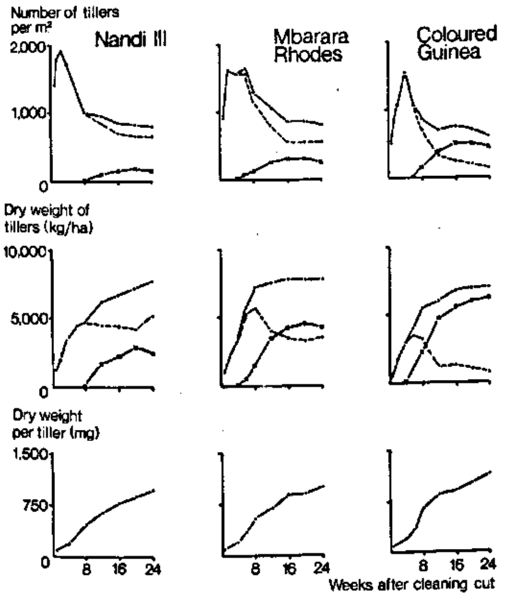

Fig. 1. The tillering patterns of three varieties in 1969; .——. total of all tillers, including non-heading tillers; .– – –. non-heading tillers; x——x heading tillers.

ties. The tillering patterns of these three varieties were basically the same in both years and, in fact, they are representative for other varieties with similar heading potential. Thus in Nandi III, Pokot Rhodes and Makueni Guinea, the percentage of heading tillers either in number or in dry weight did not exceed 50% of the total (Fig. 1, Tables 3 and 4). These are all sparsely heading varieties whether early or late heading (Fig. 2). The opposite applied to the profusely heading varieties such as Coloured Guinea and Congo Signal. It is also evident that an intermediate group is represented by Mbarara and Masaba Rhodes and Nandi I.

After the maximum tiller number had been reached, numbers decreased almost as rapidly as they had increased at first, but levelled off 1–2 months later. Final numbers were similar in most varieties. In contrast, numbers of non-heading tillers decreased

Table 4. Maximum dry weight of tillers and heading tillers (kg/ha).

Variety	1968			1969		
	tillers	heading tillers	%	tillers	heading tillers	%
Nandi I	10,720	5,030	47	8,130	5,450	67
Nandi III	10,000	3,330	33	7,750	3,000	39
Mbarara Rhodes	11,000	5,370	49	7,750	4,500	58
Masaba Rhodes	12,200	7,130	58	7,120	3,400	48
Pokot Rhodes	11,690	5,600	48	7,500	3,020	40
Coloured Guinea	8,250	5,530	67	7,100	6,250	88
Makueni Guinea	5,540	1,280	23	4,860	2,230	46
Congo Signal	12,200	7,400	61	7,350	5,840	79

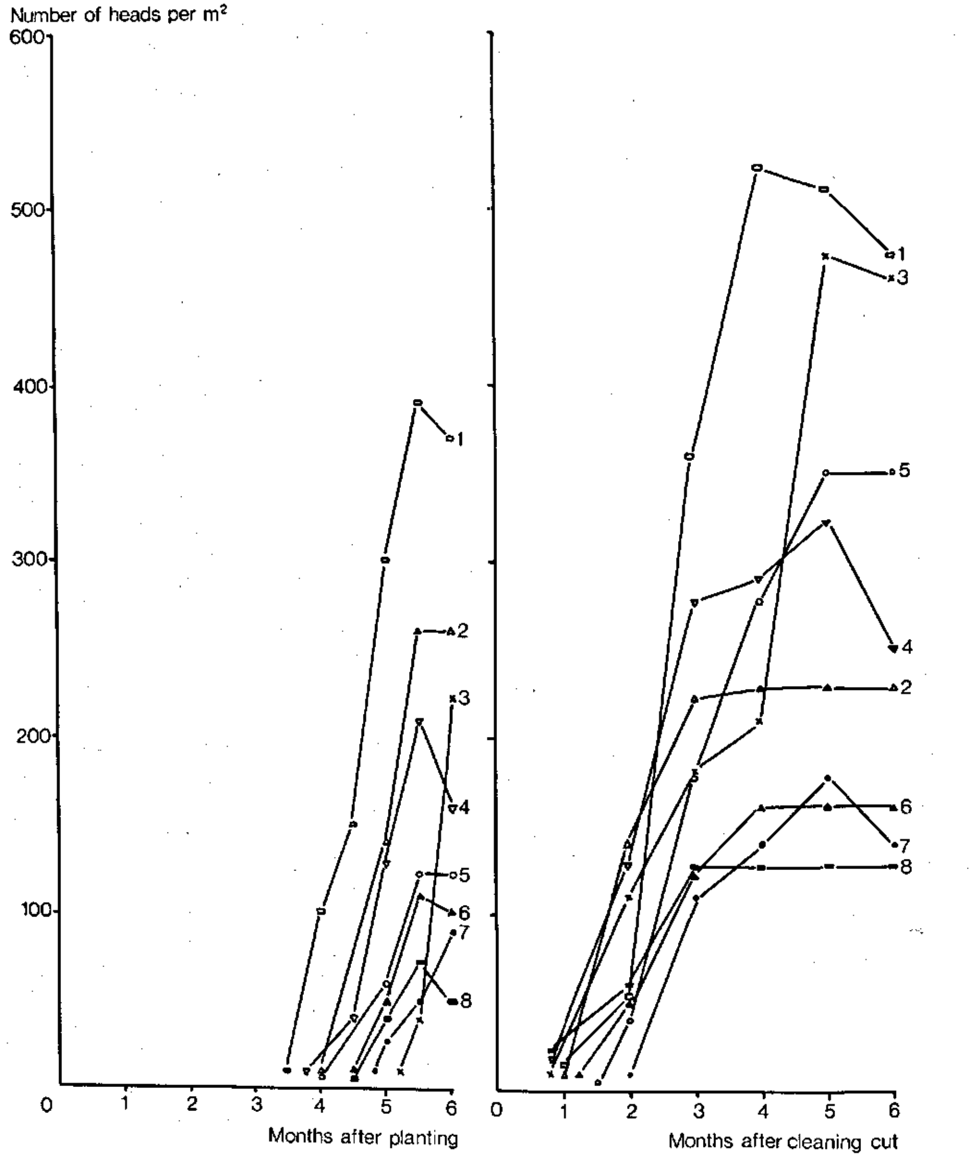

Fig. 2. Patterns of head emergence in 1968 (left) and 1969 (right). 1 = Coloured Guinea; 2 = Masaba Rhodes; 3 = Congo Signal; 4 = Mbarara Rhodes; 5 = Nandi I; 6 = Pokot Rhodes; 7 = Nandi III; 8 = Makueni Guinea.

most rapidly in varieties producing many heads, owing to the change-over from non-heading to heading tillers (Fig. 1). The complete set of data for head emergence in both years is presented in Fig. 2. It is evident that head numbers increased at an apparently linear rate for a considerable length of time. In 1968, this varied from one month in Makueni Guinea and Pokot Rhodes to two months in Coloured Guinea and Mbarara Rhodes. In 1969, heading proceeded at a linear rate over a period ranging from 2 months in Makueni Guinea and Mbarara and Masaba Rhodes to 3½ months in Nandi I.

The highest numbers of heads were produced in 1968 by Coloured Guinea (390) and in 1969 by Coloured Guinea (520) and Congo Signal (470). Nandi I produced more heads than the late-heading Nandi III, and the late-heading Pokot Rhodes produced fewer heads than Mbarara and Masaba Rhodes. Numbers were generally higher in 1969 than in 1968 except in Masaba Rhodes.

Weight of tillers

The curves representing increase in dry weight of tillers and heading tillers were parallel, a rapid initial increase being followed by a gradual levelling off (Fig. 1). Clear differences between varieties arose. In the sparsely heading Nandi III, maximum weight of heading tillers only comprised 39% of the maximum total dry weight of tillers, whereas this proportion amounted to 58% in Mbarara Rhodes and even as much as 88% in Coloured Guinea (Table 4). Alternatively, weight of non-heading tillers dropped markedly in the last two varieties after having reached a maximum in the period of early heading.

As mentioned earlier, Pokot Rhodes and Makueni Guinea reacted similarly to Nandi III in both years, while Congo Signal joined the side of Coloured Guinea. How the other varieties reacted in both years is shown in Table 4. The percentage weight of heading tillers shows whether and to what extent this weight exceeded the weight of non-heading tillers.

Total dry weights of tillers were considerably higher in 1968 than in 1969. Coloured Guinea and Makueni Guinea were the lowest yielding which confirms the empirical experience. Yield differences in the other varieties over both years were slight, but Nandi I outyielded Nandi III consistently and also reached a given weight at an earlier date.

The important differences between varieties arose from the different weight proportions of heading and non-heading tillers. Thus throughout the heading period, a larger proportion of non-heading tillers was maintained by Nandi III, Pokot Rhodes and Makueni Guinea than by Nandi I, the other Rhodes varieties and Coloured Guinea, respectively. As noted earlier, the first group of varieties is characterized by limited heading either early or late.

On the other hand it is important to note that all three Rhodes varieties and Nandi I exceeded the level of 5000 kg/ha dry weight of non-heading tillers in 1969 within 8 weeks after the cleaning cut. The level of 5000 kg/ha of total dry weight of tillers was reached within 5 weeks after the cleaning cut in Masaba and Pokot Rhodes pointing to a average growth rate of 140 kg DM ha^{-1} day^{-1}. This amount does not include the dead material and loose leaves which were discarded for the purpose of this study, although they amounted to about 10% of the total dry matter.

The dry weight per tiller was calculated on the basis of overall tiller numbers and weights. Total dry weights of tillers were higher in 1968 (Table 4), but tiller numbers were lower (Table 3), so that the weight per tiller was considerably higher in the year of planting (Table 5). It can be seen from Fig. 1 that the weight per tiller increased at a linear rate with a slight tendency to level off at the later stages of sampling. Varieties with similar weights of tillers but smaller tiller numbers had markedly heavier tillers, as is borne out in Table 5.

Table 5. Weight per tiller (mg) at IHE date of the earliest varieties.

Variety	22-7-'68	3-6-'69
Nandi I	760	260
Nandi III	390	220
Mbarara Rhodes	970	210
Masaba Rhodes	1,160	190
Pokot Rhodes	1,640	260
Coloured Guinea	520	200
Makueni Guinea	400	280
Congo Signal	910	280

It follows that tillers were much heavier in 1968 than in 1969, and that varieties with fewer tillers produced heavier tillers. Consequently, tillers were heavier in Nandi I than in Nandi III and heavier in Pokot than in Mbarara or Masaba Rhodes.

Culm length and culm branching

Data on mean culm length were obtained from 25 culms taken at random at each sampling cut in 1969 (Fig. 4).

Mean culm length increased rapidly at first and tended to level off about 16 weeks after the cleaning cut. The increase was most pronounced in Nandi, moderate in Rhodes and Coloured Guinea and only slight in Makueni Guinea. Among Rhodes varieties Mbarara Rhodes produced the longest culms. Nandi I produced longer culms than Nandi III. The longest culms were produced by Makueni Guinea followed by Nandi I.

In Coloured Guinea and Nandi it was often observed that tillers arising from elevated nodes of erect parental culms developed into flowering culms, which in turn developed nodal tillers and culms. In some instances two culms were found to arise from one single node of a parental culm. Thus far, up to eight culms have been found originating from one single tiller. Under such circumstances one could expect to find

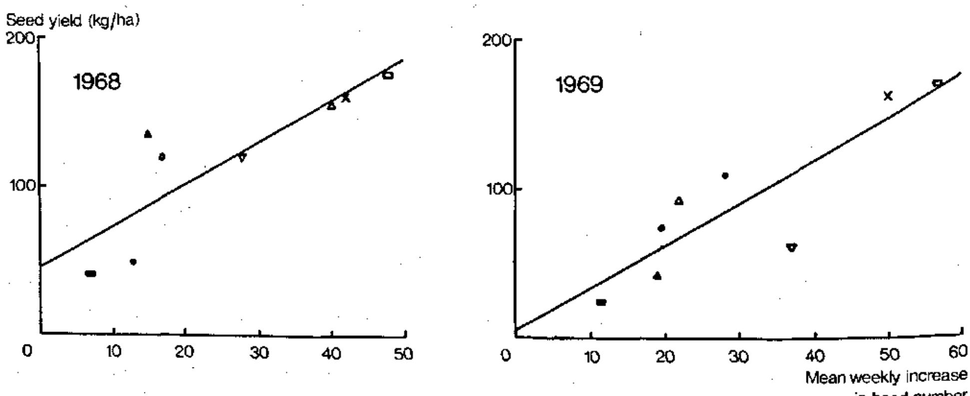

Fig. 3. The relation between maximum seed yield and mean weekly increase in head numbers prior to optimal harvesting time. For explanation of symbols, see Fig. 2. Left: 1968 ($y = 2.8x + 46.0$; $r_s = 0.85$); right: 1969 ($y = 2.9x + 4.6$; $r_s = 0.88$).

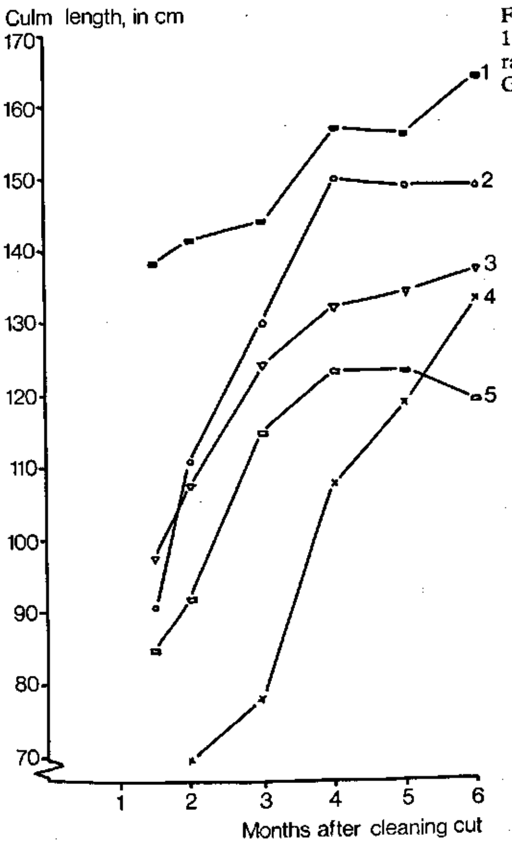

Fig. 4. Culm length in 1969 of five varieties; 1 = Makueni Guinea; 2 = Nandi I; 3 = Mbarara Rhodes; 4 = Congo Signal; 5 = Coloured Guinea.

higher numbers of tillers than when each tiller had given rise to only one heading tiller.

At this stage it is also important to mention the irregular tillering pattern of Congo Signal in 1969. It can be seen from Fig. 2 that a second rapid increase in head numbers took place between 4 and 5 months after the cleaning cut. This was associated with a rapid drop in numbers and weights of non-heading tillers which had been increasing in the previous weeks, although heading had already started in the third week. The tillering patterns of Congo Signal in 1969 were therefore characterized by having two peaks instead of just one.

The correlation between heading pattern and seed yield

Concurrent with the present study on tillering and heading, an attempt was made to study the effect of a wide range of harvesting times on seed yield in order to determine the optimal harvesting time. By so doing, it was possible to correlate the seed yields obtained at optimal harvesting time with the tillering and heading characteristics of the eight grass varieties.

It is evident from Table 6 that seed yields of varieties were closely correlated with their heading characteristics but not with tiller numbers. The closest correlation achieved was the one between seed yield and the mean weekly increase in head number over the period of six weeks prior to optimal harvesting time. This mean increase can be

Table 6. The correlation coefficients between a) seed yield and b) tillering and heading characteristics of eight grasses (r has 6 degrees of freedom).

Between seed yield and	Correlation coefficient (r)	
	1968	1969
Maximum tiller number	—0.22	—0.07
Tiller number at optimal harvesting time	0.03	—0.11
Head number at optimal harvesting time	0.80*	0.82*
Percentage of tillers heading at optimal harvesting time	0.81*	0.84**
Tillers heading at optimal harvesting time as percentage of the maximum number	0.76*	0.77*
Mean weekly increase in head number prior to optimal harvesting time	0.85**	0.88**

taken to represent the degree of concentrated head emergence of a variety. In both years Coloured Guinea showed the highest degree of concentrated head emergence and achieved the highest seed yield of all varieties. The opposite applied to Makueni Guinea (Fig. 3).

Discussion

Tillering is a dynamic process involving tiller formation and death, so that counts of tillers are only a census of an ever-changing population.

Tiller numbers rose to a maximum which roughly coincided with the period of IHE followed by a decline (Fig. 1). The patterns of tillering were similar to those observed in temperate grasses (Langer et al., 1964) and cereals (Bunting and Drennan, 1966).

Reporting on the decline in tiller numbers he observed in *Festuca rubra,* Sonneveld (1962) concluded that tiller formation stopped following elongation of flowering culms and that part of the tillers was even emptied and spent. Reviewing literature on this subject, Humphreys (1966a) pointed out that inhibition of tillering has often been related to the onset of the reproductive stage, the effect disappearing during seed maturation.

In the present study some indications arose to the effect that decreased tillering can not be explained on the basis of elongation only. First of all, the drop in tiller numbers was very marked (Fig. 1) although the onset of heading was gradual. Secondly, the phenomenon of culm branching shows that tiller formation can indeed continue on elongating flowering culms. Thirdly, a second peak of tillering and heading was observed in 1969 in Congo Signal, some two months after the first peak. Reviewing the present stage of knowledge on tillering, Dorrington Williams (1970) states that it is as yet unclear whether tiller production during flowering is suppressed by apical dominance or by insufficient light. He goes on that the onset of reproductive development is accompanied by suppression of buds borne on the flowering axes; the continued growth and production of already existing vegetative tillers can at the same time be suppressed by the reduction in light intensity resulting from the extension growth of reproductive tillers. On account of the above indications it is therefore likely that the decline in numbers was caused by reduced light intensity, the effect disappearing of the seed crop matured.

The phenomenon of culm branching as observed in Coloured Guinea and Nandi, with 'secondary' culms developing without rooting on nodes of erect flowering culms, shows that tillers can complete elongation and heading while being dependent on a parental culm. 'Secondary' culms were found to produce 'tertiary' culms. This is not in agreement with the suggestion put forward by Jewiss (1966) that tillers must be self-supporting before they themselves produce subsidiary tillers. It further shows that tiller formation is not necessarily stopped when the parental shoot begins elongation. Heading tillers elongating from elevated nodes on parent tillers have also been noticed in barley by Aspinall (1961). No references to culm branching in grasses were found, but Dirven (personal communication) also noticed culm branching in Coloured Guinea in Surinam.

Sparsely heading varieties such as Nandi III, Pokot Rhodes and Makueni Guinea appeared to maintain a dominant percentage of numbers and weights of non-heading tillers (Fig. 1, Tables 3 and 4). In profusely heading varieties such as Coloured Guinea and Congo Signal, numbers and weights of heading tillers overtook those of non-heading tillers. The occurrence of a dominant percentage of non-heading tillers does not necessarily imply that the particular variety is late-heading.

In the year of planting tillers developed on seedlings and the maximum number found did not exceed 800 per m^2 (Table 3). In the following year, 1000 or more tillers were already recorded in most varieties within two weeks after the cleaning cut (Fig. 1). Many of these were carried over from the preceding crop in a vegetative stage which was evident from the cutting marks.

The interval between cleaning cut and IHE was very short in 1969, e.g., three weeks in Mbarara Rhodes and six weeks in Nandi I (Fig. 2). This interval can be as long as 12 weeks when the preceding crop is cut at the usual stage of seed harvesting, as experienced in commercial practice. Regrowth and subsequently date of IHE appear to be delayed if the cleaning cut is carried out at an advanced stage of heading. In 1969 the cleaning cut concerned crops at the stage of early heading. According to Langer (1957), high tiller numbers produced early in the season ensure maximum regrowth. It is further evident from Fig. 1 that maximum tiller numbers were produced around IHE. Hence, it is likely that when a crop is cut at the early heading stage, regrowth will be faster and subsequent date of IHE attained earlier than when cut at a more advanced stage. It has been reported above that the regrowth amounted to over 140 kg ha^{-1} day^{-1} over the 5-week period after the cleaning cut in Pokot and Masaba Rhodes.

The sequence in which varieties start IHE depends on the kind of variety. It can be seen from Table 2 that Nandi I headed 1–3 weeks earlier than Nandi III. Mbarara Rhodes was earlier than Masaba which, in turn, headed earlier than Pokot. As in temperate grasses, heading date could be an important aid to the identification of varieties.

Another tool for varietal identification is provided by the differences in tiller numbers and weights (Fig. 1, Tables 3 and 5). Pokot Rhodes consistently showed fewer, but heavier tillers than either Mbarara or Masaba Rhodes. Nandi I produced fewer but heavier tillers than Nandi III.

In the year of planting, 1968, tillering was limited in number, but tillers were much heavier than in the second year (Tables 3 and 5). Equally, varieties with inherently smaller tiller numbers than other varieties of the same species still produced as much or even more herbage dry matter because the greater tiller weight made up for the smaller number of tillers. Because of this compensatory effect between tiller number and weight, it seems that tiller numbers, as such, can provide little information on yield.

The maximum tiller numbers found in this study were about 1,900 per m^2 in Nandi III, 1,400 in Nandi I and 1,600 in Mbarara Rhodes (Table 3). In experiments involving various row densities and levels of nitrogenous fertilizer, up to 2,800 tillers per m^2 have been recorded in Nandi II and up to 2,300 in Mbarara Rhodes (Boonman, unpublished data). Also Singh and Chatterjee (1966) found up to 2,000 tillers per m^2 in swards of an unspecified Rhodes grass variety originating from Kenya. In contrast, temperate grasses produce much higher numbers of tillers. In experiments on timothy and meadow fescue, Langer et al. (1964) observed 5,000–8,000 tillers per m^2 in established swards, although much higher numbers were found in the winter months after sowing. Fine tillered species such as *Poa trivialis, Agrostis stolonifera* and *Festuca rubra* are generally known to produce over 10,000 tillers per m^2.

It is evident from Fig. 3 that seed yield is closely correlated with the degree of concentrated heading, the percentage of heading tillers and head number. As shown in Fig. 2 head emergence may continue for 3–4 months. The optimal time of harvesting is usually reached at an early stage when head numbers are still on the increase (Boonman, unpublished data). The highly significant Correlation Coefficients ($r_6 = 0.85$ in 1968; $r_6 = 0.88$ in 1969) between seed yield and degree of concentrated heading up to harvesting time indicate that prolonged heading is a major cause of low seed yield encountered in tropical grasses.

Also important is the evidence adduced (Table 6) that high tiller numbers do not necessarily lead to high numbers of heads and high seed yield. In this respect, Nandi and Rhodes showed a contrasting relationship. In Rhodes grass, Mbarara and Masaba Rhodes produced more, albeit lighter, tillers, more heads and higher seed yields than the late heading Pokot Rhodes. In contrast, the late heading Nandi III produced more and finer tillers, but less heads and less seed than Nandi I. The three varieties of Rhodes grass were developed from entirely different ecotypes, whereas Nandi III was developed out of Nandi I (Bogdan, 1966). From the breeding point of view it is therefore tempting to suggest that plants with heavier tillers may produce many heads and high seed yields compared to the average of a population. This is also supported by the evidence noted above, that varieties produced higher seed yields in the year of planting when tillers were less numerous but heavier and producing longer heads when compared with the subsequent year.

In grasses of temperate climates, differences between heads in the date of head emergence are only a few days, whereas the tillers producing them originate over a long period from early autumn onwards (Ryle, 1966). Photoperiod is the main factor determining the time of head initiation in temperate grasses, causing tillers of very different ages to elongate and head within a very short period. In tropical grasses, however, tillering and heading both appear to be prolonged processes.

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Experimental studies on seed production of tropical grasses in Kenya. 3. The effect of nitrogen and row width on seed crops of *Setaria sphacelata* cv. Nandi II

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Summary

The effects of nitrogen levels ranging from 0 to 260 kg ha^{-1} $crop^{-1}$ and row widths varying from broadcast sowing to 100 cm were studied in two experiments over five years. By applying 100 kg N, yields of Pure Germinating Seed (PGS) and herbage dry matter were increased seven- and three-fold, respectively. The top nitrogen levels tended to decrease percentage and yield of PGS, especially at wide row width.

At 130 kg N, rows 30 cm wide produced 33 % higher yield of PGS than 90-cm rows. This resulted largely from an increase in percentage PGS, apparently brought about by more concentrated heading and flowering in general at close row width. Percentage and yield of PGS varied tremendously from season to season, although dry matter yields and head numbers varied little. The highest yield of PGS was 48 kg ha^{-1} $crop^{-1}$. It is suggested that of the various important yield components, seed setting is the one which varied most.

Rapid heading was preceded by rapid increase and subsequently rapid decline in tiller numbers.

Herbage dry matter yields were on average increased by 6.5 tons through an application of 100 kg N, i.e. 65 kg dry matter per kg N.

Introduction

In the preceding papers (Boonman, 1971a, 1971b) it was shown that head emergence and flowering within heads are prolonged processes in tropical grasses limiting the yield and viability of harvestable seed. In widely spaced seed crops of Nandi head numbers at optimal harvesting stage rarely exceed 200 per m^2 of which only part is effective. Beyond this optimal stage numbers were found to go up to 350 which exceeds the number commonly found in cocksfoot, a temperate grass with fair seed yields (Evans, 1959). Total head production may well be adequate in Nandi but achieving a more concentrated head emergence appears a prerequisite in attempting to increase seed yield.

The present study was undertaken to test the hypothesis that more even heading and maturation occur under conditions of close tiller density and appropriate nitrogen fertilization (Boonman, 1967). Tiller density ought to be such as to allow a high number of heads to emerge in a short time while suppressing the development and heading of late tillers. It was thought that the row width of 90 cm which was commonly used at that time was too wide to accomplish this.

The work reported below concerns two experiments carried out over five years and covering a range of row widths (R) from broadcast sowing to 100 cm. The accompanying nitrogen (N) levels varied from 0 to 260 kg ha^{-1} $crop^{-1}$.

The principal crop aspect studied was yield of Pure Germinating Seed (PGS). Determination of percentage PGS is important since it can vary greatly between seasons and years. It had also been observed that the yield of clean seed and the percentage PGS were differently affected by the treatments applied, especially by N. 100 kg N per ha increased the yield of clean seed in Nandi but decreased the percentage PGS (Boonman, 1968).

In view of the above considerations attempts were made to follow the tillering and heading characteristics. Attention was also directed towards analysis of seed yield components, i.e. head number, grain weight and head length, the last as a measure of spikelet number per head (Gildenhuys, 1950). Total herbage dry matter yields at seed harvesting time were also recorded, as many seed growers regard the utilization of herbage left after seed harvesting as important.

Nandi is a popular variety in Kenya and elsewhere (Hacker and Jones, 1969). The cultivar Nandi II was chosen for this study because of its greater uniformity, although it yields considerably less seed than Nandi I (Boonman, unpublished data).

Materials and methods

Exp. I was planted on 7 April 1967 and Exp. II on 8 April 1968, both at the National Agricultural Research Station in Kitale. Exp. I was in four replicates of a 3^2 lay-out three row widths, 30, 60 and 90 cm, each at three nitrogen levels, 0, 130 and 260 kg N ha^{-1} $crop^{-1}$. The crop in the 1st year, 1967, did not receive N. In 1970, the 0-level of N was changed to 65 kg. Seed was planted by hand at a constant rate per length of row, according to commercial practice, and was mixed prior to planting with single superphosphate at 50 kg P_2O_5 per ha. Top dressing with P_2O_5 was carried out annually. Row length was 8.5 m. Arrangement of plots and rows was such that plot width for harvesting was always 3.6 m, adjacent plots sharing one mutual guard-row. The field was burned once in April 1971 at the onset of the rains.

Exp. II was laid out in a 'central composite design', four treatments each at five levels in 30 plots with 2 replicates (Cochran and Cox, 1957). In addition to N and R, seed rate (0.2—1.8 kg PGS per ha) and phosphate (0—80 kg P_2O_5 per ha as single superphosphate) were studied at five equidistant levels. In the first crop after sowing, phosphate had no effect and seed rates above 1 kg PGS per ha reduced yield of PGS but not significantly (data not presented). Phosphate treatments were therefore discontinued and a flat rate of single superphosphate was applied annually. Hence N and R remained as sources of variation after the first crop. Table 4 shows the levels of N and R used. The combination $N_{100}R_{50}$, assumed to be the optimum, was adopted as the 'central point'. Rows were 10 m long and plot width for harvesting 3 m. Two guard-rows separated adjacent plots. The crop in the first year, 1968, did not receive N.

In both experiments, hand weeding was carried out only in the first year. Harvesting time was decided upon according to experience. At harvest, the whole crop was cut back with sickles, weighed and sampled for dry matter yield, bound in sheaves and stooked.

Table 1. Official rainfall figures (mm) for Kitale.

Year	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	Total
1967	3	21	104	224	258	144	190	114	58	230	84	6	1436
1968	1	147	69	201	95	127	176	121	60	88	57	18	1160
1969	62	58	107	54	215	49	101	176	116	119	52	6	1115
1970	106	9	226	144	136	89	177	205	86	83	32	14	1307
1971	9	1	21	148	118	218	181	167	75	171	60	56	1225
Long-term average	24	42	88	151	157	108	139	165	97	102	75	46	1194

Seed was beaten out two weeks later and dried in the sun or in an oven at a temperature not exceeding 40° C. Seed was cleaned on a mechanical blower, stored for some months and tested for percentage PGS. Harvested herbage was not returned to the plot. Top dressing with N was carried out in March/April at the onset of the rains, and in June/July after the first crop had been cut.

At harvesting time, samples for tillering and heading characteristics were obtained by cutting 25 cm row length in each row in a line diagonally across the plot. On various occasions heads and tillers were counted as the crop developed. For methods and definitions used see Boonman (1971b).

The rainfall data are presented in Table 1.

Results

So far, 14 harvests have been taken, eight from Exp. I since 1967 and six from Exp. II since 1968.

At each harvest observations were carried out on tiller and head numbers, percentage heading tillers, head length, culm length, yields of dry matter and clean seed, yield and percentage of PGS and 1000-grain weight. Date of Initial Head Emergence (IHE, 5-10 heads per m^2) was recorded in eight harvests. In 1968, 1969 and 1970, observations were conducted on tillering and heading at stages between cleaning cut and harvesting in a total of five crops. From 1969 onwards, stubble width was measured after each harvest to determine percentage 'stubble cover'.

The data thus accumulated, though too voluminous to present in full, provide an opportunity to report on the consistency of the results presented. Yields and percentages of PGS are listed in Table 2, 3 and 4. The relevant formula is: yield of clean seed × percentage PGS = yield of PGS. Yields of dry matter are shown in Table 5 of Exp. II only. An analysis of seed yield components, tillering and heading is presented for the July 1969 harvest of Exp. I only as this was studied in most detail (Fig. 1 and 2, Table 6 and 7). The crop failures that occurred in 1968 with yields less than 5 kg PGS are not reported separately but they are included in the averages of Table 3.

Percentages are duly given as weighted means, although this precluded statistical analysis. Yields and N rates are given in kg ha^{-1} $crop^{-1}$.

Table 2. Yields (kg/ha), percentages of Pure Germinating Seed and mean head numbers per m^2. Experiment I.

Nitrogen (kg/ha)[1]	Row width (cm)[2]	Yield of Pure Germinating Seed							Yield of clean seed (mean 1969-1971)	Number of heads/m^2 (mean 1969-1971)	percentage of Pure Germinating Seed.						
		Sept. 1967	July 1969	Nov. 1969	June 1970	Oct. 1970	July 1971	mean 1969-1971			Sept. 1967	July 1969	Nov. 1969	June 1970	Oct. 1970	July 1971	mean 1969-1971
Low	30	16.6	0.5	0.3	12.0	12.9	12.4	7.6	33	56	16.8	19.5	14.9	14.8	37.9	27.2	23.0
Low	60	12.9	0.5	0.3	17.9	16.0	23.7	11.7	49	82	13.7	21.7	15.9	16.4	32.7	29.1	23.9
Low	90	7.6	0.5	0.3	19.1	24.4	21.3	13.1	57	76	11.0	19.9	12.5	15.9	33.9	24.7	23.0
Medium	30	14.4	18.7	5.5	15.8	30.8	26.5	19.5	92	176	15.2	18.0	19.6	11.9	33.5	26.3	21.2
Medium	60	12.5	11.5	5.4	13.9	39.7	23.8	18.9	94	180	10.4	14.4	18.0	11.4	35.1	19.1	20.1
Medium	90	9.6	12.1	4.9	10.7	34.4	12.5	14.9	84	188	9.5	16.6	14.4	10.3	29.2	13.3	17.7
High	30	18.1	16.2	5.4	9.8	42.7	21.0	19.0	99	278	15.1	13.8	12.3	8.2	34.2	22.1	19.2
High	60	10.5	8.1	5.8	9.2	32.3	14.6	14.0	88	248	10.4	9.6	12.1	8.4	30.2	16.3	15.9
High	90	9.5	9.5	4.9	7.0	29.2	4.3	11.0	67	152	14.4	12.7	13.6	8.3	32.1	8.7	16.4
C.V. %		18.5	36.0	39.8	31.5	28.6	31.1	13.8	10.5	14.1							
Source of variation																	
N		—	**	**	**	**	**	**	**	**							
R		**	**	NS	NS	NS	**	**	NS	**							
N × R		—	NS	NS	*	**	**	**	**	**							

[1] Nitrogen levels: 0, 0, 0 kg N/ha in 1967; 0, 130, 260 in 1969; 65, 130, 260 in 1970 and 1971.
[2] Row width: 30, 60 and 90 cm, in text referred to as close, medium and wide row width, respectively.
* $P < 0.05$; ** $P < 0.01$; NS = not significant.

Table 3. Average yield characteristics at optimum nitrogen level (N_0 in 1967, N_{130} in 1968-1971).

Row width (R) (cm)	Yield of PGS (kg/ha)	Yield of clean seed (kg/ha)	Head number per m^2	Head length (cm)	1000-grain weight (mg)	Culm length (cm)	Number of heads at IHE per m^2	PGS (%)	Heading tillers (%)	Crop Index (%)	Cover (%)
30	15.3	79.0	159	14.0	340	136	9	19.4	19.2	0.92	69
60	14.7	81.1	169	14.9	330	133	11	18.1	23.7	0.99	44
90	11.5	72.0	160	15.1	330	132	11	16.0	23.6	0.90	34
C.V. %	11.6	7.5	9.8	3.2	3.0	2.4					
Source of variation: R	*	NS	NS	*	NS	NS					

* $P < 0.05$; NS = not significant.

Table 4. Mean yield characteristics of Experiment II over five harvests; see Table 5.

Nitrogen (kg/ha)	Row width (cm)	Yield of PGS (kg/ha)	Yield of clean seed (kg/ha)	Head number per m²	Head length (cm)	1000-grain weight (mg)	Culm length (cm)	PGS (%)	Heading tillers (%)	Crop Index (%)	Cover (%)
0	50	2.4	13	40	13.7	340	134	18.5	11	0.48	43
50	25	8.5	49	120	13.4	310	141	17.3	18	0.82	79
50	75	10.7	57	130	13.8	330	143	18.8	20	1.00	36
100	Broadcast	14.8	74	190	13.5	310	140	20.0	23	0.92	—
100	50	18.2	90	210	14.7	310	145	20.2	28	1.08	43
100	100	16.5	82	160	15.8	310	144	20.1	28	1.04	26
150	25	17.5	84	220	14.4	320	141	20.8	29	0.90	73
150	75	14.8	83	180	16.2	310	142	17.8	27	0.92	28
200	50	16.3	87	240	16.7	320	138	18.8	32	0.92	41
C.V. %		16.5	9.9	14.4	4.9	7.2	3.2				
Source of variation											
N		**	**	**	**	NS	**				
R		NS	**	NS	**	NS	NS				
N × R		**	NS	*	**	NS	NS				

* P <0.05; ** P <0.01; NS = not significant.

The yield and percentage of PGS

The superiority of adequate N and close R over the traditional N_{65} and R_{90} is borne out in Table 2, 3 and 4.

In the absence of N, yield of PGS dropped to an average of less than 2.5 kg. A sevenfold increase resulted from an additional 100 kg N. Between N_{50} and N_{150} yields more than doubled at R_{25} (Table 4).

A strong N × R interaction prevailed. Close R outyielded wide R at medium and high N but not at low N. Conversely, a pronounced response to N was confined to close R, the response to high N being small or even negative at wide R (Table 2 and 4). Apparently narrower R required more N to achieve high yield. Thus $N_{100}R_{50}$ yielded more than $N_{150}R_{25}$ (Table 4). This interaction also explains why maximum yields were produced at $N_{130}R_{30}$ in Exp. I and at $N_{100}R_{50}$ in Exp. II, as well as indicating why broadcast sowing yielded less than R_{50} at N_{100}.

In only one harvest, October 1970, did the top N-levels outyield medium N. It was also in that harvest that the highest yield of PGS was recorded, 48 kg at $N_{200}R_{50}$. There is an indication in the data that the optimum N-level was higher in crops with high yield levels.

Having established the medium N-level as the most appropriate, it is now feasible to assess the effect of R at this level (Table 3). By narrowing R from 90 to 60 or 30 cm, yield of PGS was increased by 29 and 33 %, respectively. The percentage PGS was also affected by N and R. In Exp. I is dropped with increase in N, particularly at wider R. Close R consistently produced a higher percentage PGS than wide R (Table 2). Table 3 shows that R_{30} produced 19.4 % PGS against 16.0 % at R_{90}. This and the 10 % increase in yield of clean seed from close R accounted largely for the 33 % increase in yield of PGS. However, head number, head length and percentage of heading tillers were all actually lowest at R_{30}. In Exp. II, N_{100} produced a higher percentage PGS than

Table 5. Yields of dry matter (tons/ha). Experiment II.

Nitrogen (kg/ha)	Row width (cm)	July 1969	Nov. 1969	June 1970	Oct. 1970	July 1971	Mean
0	50	3.1	1.9	1.9	2.6	2.8	2.5
50	25	7.6	5.3	6.2	5.7	5.6	6.1
50	75	7.7	5.5	5.7	5.7	5.1	5.9
100	Broadcast	8.6	7.9	8.5	9.4	7.9	8.5
100	50	9.1	8.9	9.6	8.9	8.7	9.0
100	100	8.9	8.8	8.5	8.6	7.5	8.5
150	25	9.1	10.0	10.8	9.1	10.9	10.0
150	75	9.1	9.8	9.9	9.4	10.1	9.7
200	50	9.6	10.8	10.8	11.1	9.2	10.3
C.V. %		12.5	10.3	14.6	14.1	15.0	8.0
Source of variation							
N		**	**	**	**	**	**
R		NS	NS	NS	NS	NS	NS
N × R		NS	NS	NS	NS	NS	NS

** P <0.01; NS = not significant.

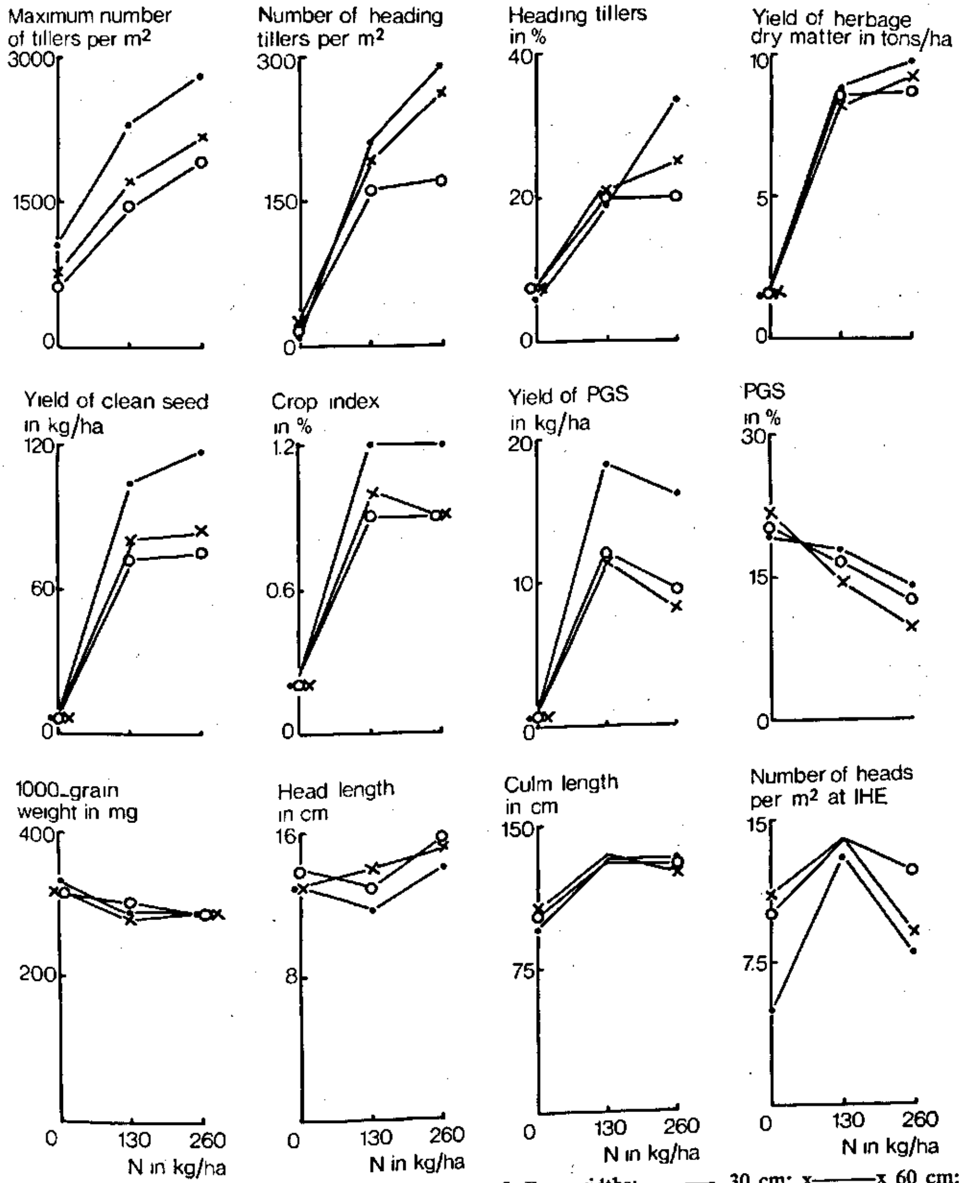

Fig. 1. Crop characteristics, July 1969, Experiment I. Row widths: .——. 30 cm; x——x 60 cm; o——o 90 cm.

the lower N-levels, and although the highest percentage was found at $N_{150}R_{25}$, a higher yield of PGS was actually obtained at $N_{100}R_{50}$ due to a proportionally higher yield of clean seed. Head numbers, head length, percentage heading tillers and 1000-grain weight were similar in both treatment combinations. It is further borne out in Table 2 that although mean head numbers were highest at N_{260}, except in wide rows, percentage and yield of PGS were lower than at N_{130}. It is therefore apparent that head numbers, when increased through high N, did not result in increased yield of PGS (see also Fig. 1).

A most striking feature of both experiments is the great variation in yield and percentage of PGS between seasons, as is evident in Table 2.

Yield of herbage dry matter

The highest yields of dry matter at seed harvesting time were produced at the top N-levels (Table 5). Top yields exceeded 10 tons per crop. In the absence of N, yields were often less than 2.5 ton per ha. By applying 100 kg N yields were increased on average by 6.5 tons, i.e. a return of 65 kg dry matter per kg applied N. There was a tendency in Exp. I of yields being higher at close R, but only at high N-level (see Fig. 1).

In contrast to seed yields, dry matter yields varied little from season to season.

Seed yield components, tillering and heading; crop of July 1969. Experiment I.

Fig. 1 shows graphs of various crop aspects. Apart from head numbers at IHE and tiller numbers when at their maximum, all observations refer to harvesting time.

N increased maximum tiller numbers, head numbers, percentage heading tillers, yields of dry matter, clean seed and PGS, Crop Index and culm length, the effects being quadratic in all cases (Fig. 1). N decreased percentage PGS and 1000-grain weight.

Most crop aspects were affected by the N $\times$ R interaction. At N_{260}, close R was superior in increasing percentage heading tillers, head number, yield of dry matter and clean seed, yield and percentage of PGS and Crop Index. Close R reduced head length. At N_{130}, differences between row widths were less marked, while at N_0 the effects were often reversed. Conversely, the effect of N was more pronounced at R_{30} than at R_{90}. As shown in Tables 3 and 4, percentage of heading tillers in close R was lower at medium N, but higher at high N.

It is also evident that although percentage heading tillers, head number and yield of clean seed were highest at N_{260}, this did not apply to yield of PGS due to a reduction in percentage PGS. This is in line with what was observed earlier in Tables 2 and 4 and it is of interest to note the general agreement between the particular crop aspects of July 1969 and those in other harvests.

The data on Crop Index indicate that seed yield suffered more from lack of N than did the yield of dry matter. (See also Table 4.)

In Fig. 2 numbers and weights of tillers are shown only since patterns of increase and decline in numbers of non-heading tillers were similar to those shown in Fig. 1 of the previous paper (Boonman, 1971b). It suffices to state that the weight of non-heading tillers was overtaken by weight of heading tillers at seed harvesting time in one treatment only, $N_{260}R_{30}$. Numbers of heading tillers remained below numbers of non-heading tillers throughout. The presentation is further simplified by the omission of the data for R_{60} which consistently fell between R_{30} and R_{90}.

The increase in tiller numbers and weights was most rapid in R_{30} at both N_{260} and N_{130}, followed by $N_{260}R_{90}$ (Fig. 2). This is also evident from the graph on maximum tiller numbers in Fig. 1. Tiller numbers were even higher at $N_{130}R_{30}$ than at $N_{260}R_{90}$,

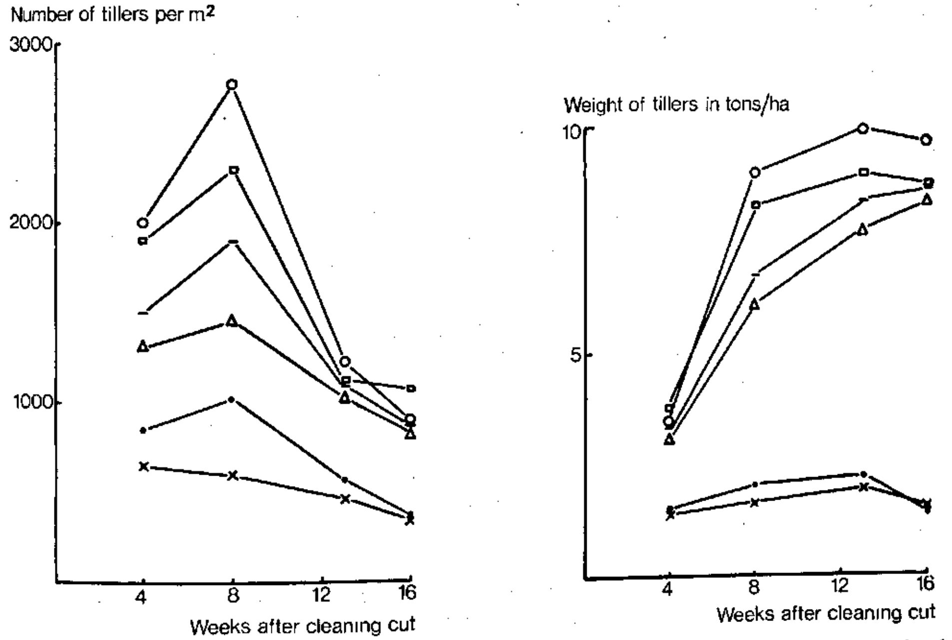

Fig. 2. Tillering in *Setaria sphacelata* cv. Nandi II, seed crop July 1969, at various nitrogen levels and row widths. o——o $N_{260}R_{30}$; □——□ $N_{130}R_{30}$; -·——- $N_{260}R_{90}$; △——△ $N_{130}R_{90}$; ·——. N_0R_{30}; x——x ; x——x N_0R_{90}.

and yet final numbers were similar at both row widths (Fig. 2). Hence decline in number was found to be most severe where the initial increase had been most rapid. For instance at $N_{260}R_{30}$ numbers of tillers dropped from a maximum of 2800 to 900 per m². Although numbers of tillers differed markedly at the first sampling date total weights differed only little, and consequently, weight per tiller was lowest at $N_{260}R_{30}$.

The numbers of heading tillers are shown in Table 6. The increase was almost linear between IHE and harvesting time. As with maximum tiller numbers, numbers of heads were highest in R_{30} at both N_{260} and N_{130}, followed by $N_{260}R_{90}$ etc. in the same

Table 6. Head numbers per m² in seed crop of July 1969 (Exp. I).

Nitrogen (kg/ha)	Row width (cm)	Weeks after cleaning cut			
		8	10 (IHE)	13	16 (seed harvest)
0	30	4	5	11	12
0	90	6	10	14	13
130	30	3	13	150	210
130	90	5	14	110	160
260	30	3	8	160	290
260	90	5	12	90	170

Table 7. Head length in seed crop of July 1969 (cm); Exp. I.

Weeks after cleaning cut	Overall head length	Length of just-emerged heads
10 (IHE)	14.6	17.7
13	14.8	13.3
16 (seed harvest)	13.8	12.9

sequence as the maximum tiller numbers of Fig. 2. This shows clearly that R was more efficient in accelerating head emergence than N. R_{90} benefitted little from the increase in N from N_{130} to N_{260}, in contrast to R_{30}.

That close R not only led to greater head numbers as such, but also to a greater number produced in a shorter length of time can be seen from the IHE graph of Fig. 1, which shows the IHE head numbers of Table 6 in more detail. Head numbers were significantly lower at R_{30}. The same trend was observed in 70 % of the crops studied for this aspect which revealed that head numbers at IHE were on average 8, 10 and 11 per m^2 at R_{30}, R_{60} and R_{90} respectively. Hence onset of heading is delayed at R_{30}. It is also evident from Fig. 1 and Table 6 that IHE head numbers were highest at medium N. This trend was also confirmed in 75 % of the crops. Both low and high N retarded the onset of heading.

An attempt was made to study variation in tiller length as a measure of stage of development. It was found that close R was characterized by the occurrence of a much higher number of longer tillers than wide R (data not presented).

Head length was increased by N and R (Fig. 1, Table 4). A comparison of overall head length and the length of just-emerged heads at different stages of heading is shown in Table 7. The length of just-emerged heads decreased after the date of IHE, but exceeded overall head length on that date. Consequently, the first emerging heads were not the longest. This was also observed in the first crop after sowing.

In the first crop after sowing, the head lengths averaged 17-19 cm, but such lengths were rare in subsequent crops, where the usual length was 13-16 cm.

Culm length varied from 110-145 cm mainly depending on N-level. Culms were shortest in the absence of N.

Discussion

The higher yielding ability of appropriate N and close R over the traditional N_{65} and R_{90} is evident. There was a good agreement between the two experiments.

Yield of PGS increased seven-fold by raising N_0 to N_{100} and two-fold from N_{50} to N_{150}, at R_{25} (Table 4). Conversely, by narrowing R_{90} to R_{30} at N_{130} yield of PGS was increased by one third.

A strong N $\times$ R interaction was prevalent. At close R more N was required to achieve high yield. On the other hand wide R responded little to N. It appears as if a row width of 30-50 cm is optimal. At current prices 1 kg PGS pays for 20 kg N.

The response to both high N and close R was most pronounced in harvests with high yield levels. Without N yields decreased rapidly after the first crop. It has also been observed that N is most efficient when applied as early as possible at the beginning of growth, since late N has little if any effect (Boonman, 1968).

A striking feature in both experiments was the huge season-to-season variation. Crops in 1968 did not even yield 5 kg PGS per ha. In contrast, the October 1970 harvests yielded a maximum of 48 kg in Exp. II and 43 kg in the fourth year running of Exp. I (Table 2 and 4). Dry matter yields were remarkably constant (Table 5). This, when considered along with the rainfall data (Table 1), does not suggest that conditions were poor for growth in general. However, low seed yields were obtained in seasons which received lower rainfall especially in the month around early heading, and vice versa. It also appeared that low rainfall during maturation was favourable for seed yield. This tendency needs to be confirmed over a wider range of years and yield records, but it does seem that seed yield is extremely sensitive to climatic variations, in contrast to herbage yields.

A response of 65 kg dry matter per kg N applied was found at N_{100} (Table 5). Yields of clean seed were very low in contrast to the high yields of dry matter, and therefore a very low Crop Index was obtained, rarely above 1 % (Fig. 1, Table 3 and 4). Seed yield was more sensitive to N than dry matter yield.

Comparing final seed yield and its components, low head numbers were invariably correlated with low seed yields (Table 2, 3 and 4, Fig. 1). Yield differences at high levels of head numbers were due to other components as well since increases in yield of PGS and head numbers were often not parallel. Of these components, 1000-grain weight was only slightly affected by treatments. As was seen in Table 3 yield of PGS was one third higher at R_{30} than at R_{90}, but values for percentage heading tillers, head number and head length were actually lowest at R_{30}. The increase in PGS yield was accounted for by an increase in percentage PGS and yield of clean seed. Hence better seed setting more than compensated for the decreased head length and number of heads.

The importance of seed setting is also evident if the large season-to-season variation between harvests with equal head numbers is considered. For instance, with 260 heads per m^2 8 kg PGS per ha were produced at $N_{260}R_{60}$ in July 1969, and no less than 48 kg at $N_{200}R_{50}$ in October 1970, i.e. a six-fold variation. The real difference was due to the seed setting, which was 3 and 18 mg PGS per head in the seasons mentioned.

It was pointed out by Langer and Lambert (1963) that yield components do not vary independently. This makes it hazardous to attach much value to correlations between yield and a single component of seed yield. For example, nitrogen increased percentage heading tillers, head number and head length, but high head numbers when increased by high N led to decreased percentage and yield PGS particularly at wide R (Table 2 and 4).

Although high N may have had a direct negative effect on seed setting, other factors may be involved. Lodging did not appear to be detrimental since high yields were often associated with bad lodging. High N may delay maturation but visual rating of seed retention in a random head sample produced no evidence to that effect. As far as the effect of N on 1000-grain weight is concerned, there was no further drop beyond medium N. The highest weight was achieved at N_0. N increased head length, which may lead to prolonged flowering and reduced seed setting per head. Bean (1969) measured the correlation between seed fertility and inflorescence size in tall fescue and found a negative correlation. It is further important to note that the top N-level reduced head numbers very markedly at wide R in Exp. I (Table 2). High N had no negative effect in the highest yielding crop, October 1970.

The effect of R on percentage PGS was more beneficial (Table 3). This can only have been brought about by more even seed maturation. It was shown in Fig. 1 and Table 6 that close R not only produced higher numbers of heads but also a delayed onset of heading. This delay may well have amounted to half a week or more as head numbers increased very slowly before IHE. Hence more heads were produced in a shorter period of time at close R. The effect of this concentrated head emergence on seed maturation may be enhanced by the shorter head length found at close R. It is possible that flowering is more even in shorter heads (Boonman, 1971a) and that this may more than compensate for any decrease in the number of spikelets in shorter heads.

Heading and tillering patterns were closely associated. The more rapid the increase in head numbers, the more rapid was the increase and subsequent decline in tiller numbers (Fig. 2 and Table 6). Treatments affected maximum head numbers and maximum tiller numbers and weights in the same sequence. Close R and high N encouraged rapid tiller and head production, the former being far more effective. An even distribution of tillers seems a prerequisite. Measurements of stubble width indicated that percentage stubble cover was 34, 44 and 69 % when R was 90, 60 and 30 cm, respectively (Table 3). The closer the row width the higher was the maximum tiller number. This may explain the greater demand for N in order to achieve high seed yield at close tiller density, and also the fact the broadcast sowing lagged behind wider R at N_{100} (Table 4). The steep drop from high maximum to almost similar tiller numbers at harvesting time appears wasteful (Fig. 2). Dying tillers may however serve a purpose in retaining and redistributing nutrients to support head development in earlier tillers, since tillers can be emptied and spent (Sonneveld, 1962). Incidentally, the lower percentage heading tillers observed at close R and medium N (Table 3) points to the existence of a larger reservoir of tillers. A more rapid drop in tiller number also signifies that formation-minus-death is less. Consequently it may be assumed that tiller formation ceases at an earlier date in the quickly closed tiller canopy of close R. The highest numbers found in these experiments were 2860 tillers and 380 heads, both at $N_{260}R_{30}$.

Ryle (1966) has pointed out that light and N increase head length. This may explain some of the effects of N and R on average head length but it is as yet unclear why the earliest formed heads were shorter than those emerging slightly later (Table 7). He also showed that seed setting efficiency decreased in late emerging heads of rye grass.

Close R also had practical advantages. A complete ecological control of weeds and volunteer seedlings was maintained in the absence of inter-row cultivation, in contrast with wide R. A more even sward is produced which facilitates mechanical cutting and removal of herbage. Finally, close R recovered more quickly after a burn at the onset of the rains.

As regards the phosphate and seed rate treatments that were applied at sowing phosphate had virtually no effect at all and seed rates above 1 kg PGS per ha reduced yield of PGS in the first crop after sowing, albeit not significantly (data not presented)

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Experimental studies on seed production of tropical grasses in Kenya. 4. The effect of fertilizer and planting density on *Chloris gayana* cv. Mbarara

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Summary

The effects of phosphate in the seed bed (0-80 kg P_2O_5 per ha), nitrogen (0-200 kg N ha^{-1} $crop^{-1}$), seed rate (0.2-1.8 kg Pure Germinating Seed (PGS) per ha) and row width (broadcast planting - 100 cm) were studied each at five levels over four years in a central composite design.

In the establishment crop, phosphate failed to affect any yield aspect, while seed rate reduced yield of clean seed and number of heads but increased yield of dry matter significantly. Seed rate and row width did not affect yield of PGS significantly. Row width decreased yield of dry matter.

In the six post-establishment crops, nitrogen was the only factor which was important for seed yield. By applying 100 kg ha^{-1} $crop^{-1}$ yield of PGS was on average increased more than sixfold, to 41 kg ha^{-1} $crop^{-1}$ at a row width of 50 cm. Yield of PGS was highest at 25 cm row width and 150 kg N per ha, but the effect of row width was not significant. Row width however increased yield of dry matter and number of heads. Increases in nitrogen and row width accelerated the onset of heading.

Introduction

In my previous paper (Boonman, 1972) it was shown that adequate nitrogen (N) and close row width (R) increased yield of Pure Germinating Seed (PGS) considerably in *Setaria sphacelata* cv. Nandi II. Phosphate (P) and seed rate (SR) had no significant effect in the establishment crop.

The object of the present study was to investigate the effects of the same factors on Rhodes grass, *Chloris gayana* cv. Mbarara. Although Rhodes grass is a stoloniferous species, the original sowing lines remain distinguishable for several years; this is particulary evident after a burn.

Mbarara Rhodes is widely grown in Kenya (Bogdan, 1969). It is early heading and a relatively good seeder (Boonman, 1971).

Materials and methods

The design, treatments and operations were the same as those described for Experiment II of my previous paper (Boonman, 1972). Both experiments ran concurrently. The first planting on 17 April 1968 failed. Seed was replanted without phosphate into the original lines on 17 July 1968. Samplings for tillering and heading were carried out in the first two crops. These proved to be difficult to carry out because of the dense stands and were not repeated in subsequent crops. In the 1970 crops Initial Head Emergence was estimated (IHE, 5-10 heads per m^2).

To cope with the numerous samples for PGS testing, a quick routine method was developed. Seed samples were first cleaned sharply on a 'Brabant' clipper. Germination was tested on ordinary zinc trays in a greenhouse. During daytime, a temperature of 30° C or just above was maintained under the bell jars by replacing part of the water in the trays with boiling water in the morning. The greenhouse was heated with charcoal stoves when the temperature dropped below 30. It rarely dropped much below 20 at night.

Results

Seven harvests have been taken up till 1972. At each harvest observations were carried out on tiller and head numbers, percentage heading tillers, yields of dry matter and clean seed, percentage and yield of PGS, raceme characteristics, 1000-grain weight, culm length, seed retention and lodging.

This paper is confined to reporting on important comparisons and points of difference with the previous paper (Boonman, 1972). The data for the establishment crop harvested in December 1968 are presented in Table 1, while Table 2 shows the averages of the six post-establishment crops. Table 3 gives the yields and percentages of PGS at 0, 100 and 200 kg N ha^{-1} crop^{-1}. In Table 4 the crop-to-crop variation is presented for

Table 1. Yield characteristics of the establishment crop, December 1968.

Seed rate (kg/ha)	Row width (cm)		Yield of clean seed (kg/ha)	PGS %	Yield of PGS (kg/ha)	Yield of dry matter (tons/ha)	Number of heads per m^2
0.2	50		145	33.4	48.5	7.3	410
0.6	25		117	46.1	53.9	7.9	360
0.6	75		143	40.1	57.3	6.9	350
1.0	Broadcast		160	45.6	73.0	7.3	400
1.0	50 (central point)		125	45.2	56.5	7.8	350
1.0	100		155	31.0	48.0	6.4	420
1.4	25		96	48.2	46.3	8.6	340
1.4	75		125	44.3	55.4	7.3	340
1.8	50		110	43.6	48.0	8.3	310
		C.V. %	20.8	—	24.2	9.1	12.6
Source of variation		SR	*	—	NS	*	*
		R	*	—	NS	**	NS
		P	NS	—	NS	NS	NS
		interactions	NS	—	NS	NS	NS

*P < 0.05; **P < 0.01; NS = not significant.

Tabel 2. Average yield characteristics in post-establishment crops (6 crops, 1969—1971).

Nitrogen per crop (kg ha-1)	Row width (cm)	Yield of clean seed (kg/ha)	PGS (%)	Yield of PGS (kg/ha)	Yield of dry matter (tons/ha)	Crop In-dex (%)	Number of heads per m²	Heading tillers (%)	Number of ra-cemes per head	Mean raceme length (cm)	1000-grain weight (mg)	Seed reten-tion (1-5)[1]	Culm length (cm)	Lodg-ing (1-5)[2]	Head numbers in crops of 1970: IHE	Head numbers in crops of 1970: seed harvest
0	50	16.0	38.7	6.2	2.1	0.8	67	15	8.3	6.9	290	4.4	103	5.0	3	40
50	25	48.1	37.8	18.2	4.7	1.0	129	21	9.4	6.8	270	4.2	116	4.8	8	100
50	75	50.1	39.7	19.9	4.8	1.0	147	24	9.4	6.9	260	4.3	115	4.7	8	100
100	Broadcast	89.0	41.2	36.7	6.8	1.3	207	28	9.7	6.8	250	4.2	119	3.8	9	160
100	50 (central point)	96.7	42.4	41.0	6.9	1.4	240	35	10.2	6.9	270	4.1	120	3.5	13	190
100	100	102.0	39.9	40.7	7.3	1.4	264	37	9.9	7.0	280	4.0	119	3.2	15	230
150	25	107.0	40.4	43.2	7.3	1.5	257	42	10.6	7.1	280	4.0	122	2.5	14	210
150	75	108.9	37.8	41.2	7.7	1.4	276	46	10.9	7.2	280	4.0	120	2.2	20	210
200	50	110.0	39.0	42.9	7.4	1.5	293	47	10.6	7.3	290	3.9	121	2.2	20	170
	C.V. %	11.5	—	14.5	6.4	—	11.7	—	3.0	3.1	4.9	3.3	2.9	10.5	19.5	21.2
Source of variation	N	**	—	**	**	—	**	—	**	**	*	**	**	**	**	**
	R	NS	—	NS	*	—	**	—	*	NS	NS	NS	NS	NS	**	NS
	N × R	NS	—	NS	NS	—	NS	—	NS	NS	NS	NS	NS	NS	**	NS

* $P < 0.05$; ** $P < 0.01$; NS = not significant

[1] Seed retention: 5 = no shedding; 1 = all seed shed. Visual estimation of 25 random heads per plot at seed harvest.

[2] Lodging: 5 = no lodging; 1 = lodged flatly. Visual estimation at seed harvest.

the central point of the design. Table 5 shows some raceme characteristics as observed in the second crop.

Establishment crop

The highest yield of PGS in the whole experimental period, 73 kg per ha, was achieved in the establishment crop with the combination of broadcast planting and medium SR (Table 1). The yield of clean seed was also highest with this treatment, but was reduced by seed rates above 1 kg. The percentage of PGS was highest at $SR_{1.4}R_{25}$, i.e. at high planting density. The same applied to yield of dry matter. Yield of PGS was not significantly affected by SR and R.

Tiller numbers were highest at $SR_{0.2}R_{50}$ in all samplings of the heading period. R had little effect but SR decreased numbers significantly except at time of seed harvest (data not presented). At this time SR decreased head numbers significantly (Table 1). R and SR had no significant effect on raceme length and raceme number per head, 1000-grain weight and percentage of heading tillers while culms were significantly shorter at wide R (data not presented). All these variables were rather high compared with most subsequent crops (Table 4).

P did not affect any aspect of yield. Hence treatment levels were not continued in the post-establishment crops.

Post-establishment crops

No effect of SR was found. N emerged as the most important factor. Yield of PGS was increased more than sixfold by the application of 100 kg N ha^{-1} $crop^{-1}$ (Table 2). Increasing N from 50 to 100 kg doubled the yields. The effect of R was not significant. The highest yield, 43.2 kg, was achieved at $N_{150}R_{25}$. The top N levels increased the yield of PGS slightly. On the average they increased the yield of clean seed but tended to decrease the percentage of PGS (Table 2 and 3). N_{200} outyielded N_{100} in two harvests, October 1970 and November 1971, both having high yield levels (Table 3). In the absence of N yields were still high in the first post-establishment crop but subsequently dropped to as little as 2 kg per ha. The high yield obtained with N_0 in July 1971 could be attributable to the increased nitrogen mineralized after the extremely dry season 1970/1971.

Number of heads and number of racemes per head increased significantly with N and R. N trebled the percentage of heading tillers, R having a slightly positive effect. N increased mean raceme length and 1000-grain weight significantly (Table 2).

Table 3. Yields and percentages of Pure Germinating Seed (PGS) of post-establishment crops at row width of 50 c[m]

Nitrogen (kg/ha)	Yield of PGS (kg/ha) July 1969	Oct. 1969	July 1970	Oct. 1970	July 1971	Nov. 1971	mean	Percentage of PGS July 1969	Oct. 1969	July 1970	Oct. 1970	July 1971	Nov. 1971	mean
0	13	3	2	5	11	4	6.2	55	36	47	39	34	26	38.7
100	34	42	27	32	51	60	41.0	63	39	37	40	37	47	42.4
200	20	36	26	63	40	71	42.9	58	27	48	44	31	44	39.0

Table 4. Crop characteristics at the central point of design.

Crop characteristics	Dec. 1968	July 1969	Oct. 1969	July 1970	Oct. 1970	July 1971	Nov. 1971
Yield of clean seed (kg/ha)	125	53	107	74	81	137	128
Percentage PGS	45	63	39	37	40	37	47
Yield of PGS (kg/ha)	57	34	42	27	32	51	60
Yield of dry matter (tons/ha)	7.8	6.5	8.4	7.9	7.5	6.7	4.2
Crop Index (%)	1.6	0.8	1.3	0.9	1.1	2.1	3.0
Number of heads per m²	350	320	110	250	120	330	310
Percentage heading tillers	51	38	20	36	—	51	46
Number of racemes per head	11.1	8.2	10.9	11.5	10.0	11.1	9.4
Average raceme length (cm)	7.1	6.5	7.0	7.0	7.1	7.0	6.9
1000-grain weight (mg)	320	290	270	220	250	290	300
Seed retention (1-5; 5 = no shedding)	—	—	4.5	3.9	4.7	4.1	3.3
Culm length (cm)	130	129	128	123	—	—	100
Lodging (1-5; 5 = no lodging)	—	3.4	2.0	4.9	3.0	4.1	3.5

The data on seed retention indicate that N increased shedding. This was undoubtedly so because N accelerated IHE (Table 2). R did the same but the effect was less pronounced. In the experiments on Nandi previously described (Boonman, 1972) numbers at IHE were highest at medium N.

In the crop of July 1969 tillers were counted at 3-4 weekly intervals. A significant response to R was found at the first sampling only, when tiller numbers were highest at R_{100} (data not presented). However R decreased tiller numbers in the Nandi experiments of my previous paper (Boonman, 1972). Nandi produced more tillers than Mbarara and tillers were fewer but heavier in the establishment crop.

Table 5 shows the average raceme characteristics of the same crop for various dates of sampling. Values were higher on 17 June than at IHE and at seed harvest. This is in line with the findings on head length in Nandi as described in the previous paper.

N and R increased the yield of dry matter significantly (Table 2). Yields were low in the fourth year, 1971 (Table 4). N increased culm length and lodging significantly (Table 2) while R tended to increase lodging also, but the effect was not significant. N nearly doubled the Crop Index, R having no effect. An unusually high Crop Index, 3.0 %, was observed for the November 1971 harvest (Table 4). High yield of clean seed was accompanied by a low yield of dry matter. This crop was also characterized by a low culm length.

Table 5. Average raceme characteristics, seed crop July 1969.

Date	Number of racemes per head	Length per raceme (cm)
27 May (IHE)	9.1	7.0
17 June	9.9	7.3
10 July (seed harvest)	8.3	6.7

Discussion

The most striking difference between the above results and those of the experiments on Nandi described previously (Boonman, 1972) was the observation that yield and percentage of PGS were about twice as high in Mbarara (Table 2, 3 and 4). Yields did not vary as much from crop to crop. Yields of dry matter were lower and tended to go down from the fourth crop onwards whereas seed yields did not show this trend. If the decline in yield of dry matter mirrors the lack of persistency that Mbarara normally displays in contrast with Nandi, this may be due to the higher percentage of heading tillers and lower tillers numbers found in this experiment compared with the Nandi experiments. It is, however, worth noting that yields of PGS were highest in the last crop (Table 3 and 4).

The response to N, R, SR and P was basically the same as found before (Boonman, 1972).

N was the most important factor in growth of the post-establishment crops. Whereas high N decreased yield of PGS considerably in Nandi, N_{150} and N_{200} continued to increase yield in Mbarara, although percentage of PGS was slightly reduced. The optimum level is about 100 kg N ha^{-1} $crop^{-1}$.

The effect of R on yield of PGS was not significant but close R outyielded wide R at high N (Table 2). This was mainly due to the positive effect of close R on the percentage PGS since yield of clean seed tended to be higher at wide R.

In the establishment crop broadcast planting produced the highest yield. The highest average yield of PGS in the post-establishment crops was achieved at $N_{150}R_{25}$ (Table 2). However yield of clean seed, head numbers and other heading characteristics were actually lower at this treatment than at $N_{200}R_{50}$ and $N_{150}R_{75}$, which came second and third in yield of PGS. The higher yield of PGS in the first treatment, $N_{150}R_{25}$, was brought about by a proportionally higher percentage of PGS. As discussed before (Boonman, 1972) this increased percentage of PGS is most likely due to the more concentrated heading in this treatment combination since N and R accelerated IHE (Table 2) and possibly also due to a more even maturation in short racemes.

As N accelerated heading it also increased shedding (Table 2). This was unexpected since heads in high N plots usually look darker at harvesting time than heads in low N plots.

Despite a range of 0.2-1.8 kg PGS per ha, SR had no significant effect on yield of PGS in the establishment crop nor, as could be expected, in subsequent seed crops. There was a tendency for yields to be reduced by SR above 1 kg as in the Nandi experiments (Boonman, 1972). Rates below 1 kg appeared less harmful than those above. There was no R $\times$ SR interaction. Thus SR does not need to be increased to suit close R. Assuming 50 % failure and a 1000-grain weight of 250 mg, 1 kg PGS when planted in 50-cm rows still produces one seedling per cm row length. Stiff competition therefore ensues from high seed rates, particularly in wide rows. Seed take, however, is often determined more by environmental conditions than by seed rate alone.

It is important to note that density had a greater effect on dry matter yield and head number than on yield of PGS, both in the establishment crop and thereafter.

P was not found to have any effect on yields in the establishment crop (Table 1). Dougall (1954) and Holme and Sherwood (1954) have shown that the effect of P on grasses in the Kenya Highlands was limited, except when applied in the seed-bed to promote rapid establishment. In trials carried out by me on the red sandy clays derived from the basement complex around Kitale, grass establishment was promoted in some cases and reduced in others by P. The negative effect of P was probably due to scorching of the seed after planting. In some trials no effect was noted. In another trial six consecutive crops were harvested for seed with complete removal of herbage following a single top dressing with rates varying from 0-80 kg P_2O_5 per ha. No response to P was found in any of the harvests but yields of seed and herbage were normal (Boonman, unpublished data). These trials were carried out on soils that had received P in the past at varying amounts. It is difficult to base the need for P on soil analysis because even in maize which responds very well to P, little correlation exists between soil analysis data and yield response to applied P (Osborne and Allan, 1971). Grass seed is seldom the first crop in an arable break and normally follows maize which is liberally supplied with P. It seems advisable to confine the heavy dressings of P to the cereal break and only to apply a little P in the seed-bed of the grass seed crop.

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Experimental studies on seed production of tropical grasses in Kenya. 5. The effect of time of nitrogen top dressing on seed crops of *Setaria sphacelata* cv. Nandi

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Summary

The effect of time of nitrogen top dressing on early-season and late-season seed crops of *Setaria sphacelata* cv. Nandi was studied in four experiments during the period 1967—1971.

Nitrogen gave the best results when applied as soon as possible after the onset of the rainy season. A delay of four weeks decreased yield of Pure Germinating Seed (PGS) by more than 60 %. Total yield of herbage dry matter and head numbers were also negatively affected but to a lesser extent. The main seed yield component reduced by late applied nitrogen was the seed set per head.

In the late-season crops, a delay in top dressing of two weeks after the earliest possible date proved beneficial in two out of three years.

Introduction

Nitrogen (N) being the major factor determining seed yield in *Setaria sphacelata* cv. Nandi (Boonman, 1972), it is imperative to assess the optimal time of aplication in relation to stage of crop development and climatic conditions.

The present study describes 4 experiments undertaken to investigate the effect of time of N application both at fixed and varied dates of cleaning cut. Exp. 1 was designed to determine the effect of split application. It was found that late applied N had no beneficial effect, and this raised the question of whether this was due to season or to the advanced stage of growth at the time of application. To clarify the issue, the following experiments were subsequently initiated:

— Exp. 2: data of cleaning cut (C) was varied, N being applied directly after cutting;

— Exp. 3 and 4: date of cleaning cut was fixed but time of N application (T) was varied.

The latter two experiments are very relevant to current commercial practice. Seed fields are normally cut for hay or grazed in the dry season, December—March, so that little herbage is present at the onset of the rains. Nevertheless, many seed growers do not top dress until May or even later, since other farm work receives greater priority. Quite apart from the effect this delay has on the yield of the early-season crop, less of the rainy season is left for the subsequent development of a late-season seed crop.

If, however, the first crop has been taken early and a second crop is envisaged, the question again arises as to when N should be applied to ensure maximum yield. Ideally, the seed grower should have sufficient time at his disposal to utilize the herbage left over from the first crop before top dressing is required for the second crop.

Only post-establishment crops are considered in this study as no nitrogen is normally applied to the establishment crop.

Materials and methods

Exp. 1 (1967) was laid out in a seed field planted in 1964 with *Setaria sphacelata* cv. Nandi I. The lay-out was a replicated 4 × 2 factorial, with 4 levels of N applied either as a single dressing on 17 April, 2 weeks after the onset of the rains, or as a split dressing with half on 17 April and half on 6 June (Table 1). The latter date was 1 week after IHE (Initial Head Emergence, 5-10 heads per m^2) and 6 weeks before the seed harvest on 15 July.

Exp. 2 (1970) was carried out in a seed field planted in 1969 with Nandi II. Treatments consisted of different dates of cleaning cut, spaced 2 weeks apart (Table 2). A top dressing with 100 kg N immediately followed the cleaning cut. The seed harvest was carried out 6 weeks after IHE in the treatment concerned. On the date of harvest all herbage was removed and another top dressing at 100 kg N per ha was applied.

Exp. 3 (1969 and 1970) was laid out in a seed field planted in 1968 with Nandi II. At equal intervals 100 kg N per ha were applied, the base date being the day on which all treatments received the cleaning cut (Table 3). A control with no-N was included. All treatments were harvested for seed on the same day.

Exp. 4 (1971) was situated in the same field as Exp. 2. The field was burnt on 10 February and the rains broke in early April. Table 4 shows the dates when 100 kg N per ha were applied to the treatments, which were arranged in a latin square design.

All experiments were in 4-5 replicates on fields in which the rows were spaced 80-90 cm apart. N was applied in the form of ammonium sulphate nitrate. Single superphosphate was applied annually. Harvesting and sampling were carried out as described previously (Boonman, 1972). For monthly rainfall data see Boonman (1972).

With the exception of 1967 and 1971, when the rains had a clear-cut beginning after rainless dry seasons, determination of the base date for treatments in the other years with wet 'dry' seasons was slightly arbitrary. The harvest date of the early-season crop functioned simultaneously as the base date for the late-season crop.

Results

N increased head number, head length and yield of clean seed significantly in Exp. 1, but the effect on yield of Pure Germinating Seed (PGS) was not significant (Table 1). Splitting the application had a significant, negative effect on yields. $N_{34/0}$ outyielded $N_{17/17}$ as well as $N_{34/34}$. Similarly, $N_{68/0}$ outyielded $N_{34/34}$ as well as $N_{68/68}$.

Split application had no significant effect on head number. This in fact means that the second half of the application had a similar effect in raising head numbers as the first half, the difference being that the second half increased the number of late emerging heads. As a result, overall mean head length was reduced by split application, while the significant interaction indicates that the response to increased N was better in the single application. Treatments had no effect on 1000-grain weight or percentage of PGS.

Table 1. The effect of split application of nitrogen on a seed crop of Nandi I; cleaning cut 17 April, harvest 15 July 1967. Experiment 1.

Nitrogen (kg/ha)		Yield of clean seed (kg/ha)	PGS (%)	Yield of PGS (kg/ha)	Head number per m²	Head length (cm)	1000-grain weight (mg)
17 April	6 June						
34	—	128	38	49	240	13.7	380
68	—	145	39	57	270	13.7	370
102	—	162	33	54	330	14.3	310
136	—	161	39	63	300	16.5	360
17	17	110	39	43	200	12.1	370
34	34	109	38	41	210	12.5	390
51	51	141	39	55	280	14.5	350
68	68	139	36	50	310	12.5	410
C.V. %		13.0		22.6	14.4	4.9	35.1
Source of variation							
Nitrogen		**		NS	*	*	NS
Split		**		*	NS	**	NS
Nitrogen × Split		NS		NS	NS	**	NS

*P <0.05; **P <0.01; NS = not significant.

By delaying cleaning cut (C) and simultaneous top dressing, by 2 and 4 weeks, yield of PGS declined by 19 and 65 %, respectively, in the first crop of Exp. 2 (Table 2). The main yield component responsible for this decline was the percentage of PGS which was highest at C_1, whereas yield of clean seed and head number were highest at C_2. Yield of dry matter also decreased. The apparently better growing conditions in the early part of the season were also reflected in the intervals between C and IHE. These intervals increased from 9 to 11 weeks as C was delayed. The 1000-grain weight increased also. In the unclean seed the weight percentage of spikelets with bunt *(Tilletia echinosperma)* was more than doubled at C_6 compared to C_1.

In the second crop of Exp. 2, however, yield of clean seed, yield and percentage of PGS were much higher at C_2, 16 July, than at C_1, 3 July (Table 2). Later cuts resulted in a further decline of yield, and the last cut did not produce a crop at all since its IHE fell right in the dry season. Except at the last cut, intervals between cleaning cut and IHE were 11 weeks. The higher degree of shedding in the later cuts may indicate that seed maturation was more rapid as the dry season came nearer. Both the 1000-grain weight and the weight percentage of bunted spikelets in the unclean seed reached a maximum at the third cut. The 1000-grain weights of the second crop were higher than those of the first.

In Exp. 3 and 4, date of cleaning cut was not varied, so that effects of crop stage and time of application were confounded. In Exp. 3 (1969 and 1970), herbage was cut back in all treatments on the same base date (T_1). In Exp. 4 (1971), the field was burnt during the dry season and the base date (T_1) immediately followed the very sudden onset of the rains in that year. Since date of IHE in the first crops was not affected by T, treatments were all harvested on the same day.

In the early-season crops a delay in top dressing of only two weeks caused a decline in yield of PGS of 10, 58 and 46 % in 1969, 1970 and 1971, respectively. The corresponding decreases caused by a delay of 4 weeks were 65, 76 and 62 % (Table 3 and 4). In Exp. 3, yields at T_4 were nearly as low or even lower than at no-N (Table 3). Yields

Table 2. The effect of delayed cleaning cut and top dressing on seed crops of Nandi II, 1970. Experiment 2.

Date of cleaning cut and N top dressing	Interval till IHE (weeks)	Date of seed harvest	Yield of clean seed (kg/ha)	PGS (%)	Yield of PGS (kg/ha)	Yield of dry matter (tons/ha)	Head number per m²	Heading tillers (%)	1000-grain weight (mg)	Bunt in unclean seed (%)	Seed shedding (1-5; 5 = no shedding)
First crop											
20 March	9	3 July	74	11.4	8.4	11.6	137	41	250	20	NR
3 April	9	16 July	86	7.9	6.8	10.9	150	43	260	25	
17 April	9	30 July	75	3.9	2.9	9.1	95	19	290	26	
1 May	10	19 August	57	4.2	2.4	9.1	72	14	290	37	
15 May	10	5 September	62	1.9	1.2	8.4	76	19	310	40	
29 May	11	28 September	60	4.2	2.5	8.6	76	20	350	46	
LSD (0.05)			12		3.3	1.3	19		40		
LSD (0.01)			17		4.1	1.8	26		60		
Second crop											
3 July	11	28 October	95	8.7	8.3	NR	132	NR	260	27	4.4
16 July	11	11 November	139	22.7	31.5		174		380	25	4.2
30 July	11	25 November	56	11.8	6.6		113		460	31	4.1
19 August	11	9 December	40	9.5	3.8		79		420	27	3.9
5 September	11	23 December	12	5.0	0.6		40		380	19	4.1
28 September	12	(no crop)									
LSD (0.05)			36		12.2		35		80		0.3
LSD (0.01)			49		17.7		49		110		0.4

NR = no record taken.

Table 3. The effect of time of nitrogen application on yields in seed crops of Nandi II in 1969 and 1970. Experiment 3.

1st crop 1969 (cleaning cut 14 April, harvest 1 August)			1st crop 1970 (cleaning cut 30 March, harvest 13 July)		
nitrogen (date)	yield of PGS (kg/ha)	yield of dry matter (tons/ha)	nitrogen (date)	yield of PGS (kg/ha)	yield of dry matter (tons/ha)
14 April	10.1	10.0	1 April	5.5	10.8
28 April	9.1	9.3	15 April	2.3	9.2
12 May	3.5	9.1	29 April	1.3	8.8
26 May	2.2	7.0	13 May	0.6	7.1
No N applied	3.4	5.3	No N applied	0.6	2.6
LSD (0.05)	2.3	1.9		1.1	1.4
LSD (0.01)	3.1	2.6		1.5	1.9

2nd crop 1969 (cleaning cut 1 August, harvest 26 November)			2nd crop 1970 (cleaning cut 13 July, harvest 10 November)		
nitrogen (date)	yield of PGS (kg/ha)	yield of dry matter (tons/ha)	nitrogen (date)	yield of PGS (kg/ha)	yield of dry matter (tons/ha)
2 August	6.0	6.0	14 July	15.3	10.0
23 August	2.4	4.9	28 July	20.2	10.6
13 September	2.4	4.3	11 August	7.3	9.4
4 October	1.8	4.1	25 August	-	-
No N applied	-	2.3	No N applied	-	-
LSD (0.05)	1.6	1.0		7.4	NS
LSD (0.01)	2.2	1.4		10.7	NS

NS = not significant.

of dry matter (Table 3) and head numbers (Table 4) also decreased progressively, but to a much lesser extent. Seed yields were generally much higher in 1971 than in 1970 and 1969.

Table 5 shows that late applied N increased the number of non-heading tillers at the advanced stages of growth, when compared with early applied N and no-N. The decline in numbers was most pronounced in the case of early applied N.

In the late-season crops, yields of PGS and dry matter were higher at T_1 in 1969 only (Table 3). In 1970 and 1971, yield of PGS and dry matter as well as yield of clean seed, percentage PGS and head number were highest when N was applied 2 weeks after the cleaning cut. Unlike the early-season crops, the late-season crops produced IHE and shedding earlier with early N application (Table 4). This increase in shedding may have decreased PGS yield at T_1.

Discussion

It is evident that split application was disadvantageous (Exp. 1), that cleaning cut and subsequent top dressing should be carried out early in the rainy season (Exp. 2) and that top dressing should follow soon after the cleaning cut (Exp. 3 and 4). A delay of 4

Table 4. The effect of delayed nitrogen application on seed crops of Nandi II, 1971. Experiment 4. (First crop harvested on 23 July, followed by a cleaning cut on 7 August. Second crop harvested on 22 December).

Date of nitrogen application	Head number per m² at IHE	Yield of clean seed (kg/ha)	PGS (%)	Yield of PGS (kg/ha)	Head number per m² at harvest	1000-grain weight (mg)	Seed shedding (1-5; 5 = no shedding)
First crop							
5 April	4.4	151	47	71	310	610	NR
19 April	4.6	113	34	38	280	580	
26 April	5.0	77	35	27	270	580	
3 May	4.3	60	32	19	220	600	
10 May	7.1	59	36	21	200	600	
LSD (0.05)	NS	24		15	40	NS	
LSD (0.01)	NS	33		21	50	NS	
Second crop							
13 August	NR	63	37	23	210	630	4.0
20 August		88	48	42	260	610	4.2
27 August		100	50	50	250	620	4.3
3 September		89	45	40	240	620	4.6
10 September		68	46	31	200	600	4.6
LSD (0.05)		20		5	40	NS	0.4
LSD (0.01)		29		7	60	NS	0.6

NS = not significant; NR = no record taken.

Table 5. The effect of nitrogen application on numbers of non-heading tillers; 1969, 1st crop, cleaning cut 14 April, IHE 13 June, harvest 1 August. Experiment 3.

Nitrogen applied (date)	Number of non-heading tillers per m²			
	30 April	13 June	11 July	1 August
14 April	2020	1040	430	250
26 May	2010	1200	1200	620
No N applied	1770	1190	870	430
LSD (0.05)	NS	NS	200	250
LSD (0.01)	NS	NS	280	NS

NS = not significant.

weeks in cleaning cut and/or top dressing reduced PGS yield by more than 60 % (Tables 2, 3 and 4). Additional advantages of an early first crop are the higher yields of dry matter (Table 2 and 3), the reduced incidence of bunt *(Tilletia echinosperma)* and the ample time left for utilizing the herbage before top dressing is required for the second crop.

The response to N was largely governed by season, but stage of growth limited the effect of season. N, when applied 6 weeks after the cleaning cut, produced no more than the no-N treatment (Table 3). Table 5 showed that late applied N increased the number of non-heading tillers at advanced stages of growth and, presumably, also the number of late heading tillers. If this is accepted, it becomes clear why head numbers were very much the same in the single and split application of Table 1 and also why heads were on avarage shorter in the split application. PGS yields were however lower with late applied N, probably because late heads are likely to develop at the expense of seed maturation in early heads without compensating for the latter. There was no evidence that late N increased 1000-grain weight. In *Paspalum plicatulum,* Chadhokar and Humphreys (1970) observed that seed production was independent of N nutrition after head emergence.

In a recent study of a seed yield experiment on *Setaria sphacelata,* involving various varieties, N levels, harvest dates and row widths, Hacker and Jones (1971) also reported a slight, albeit not significant, reduction in yield of clean seed from split application. N, varying from 42 to 336 kg per ha applied in 2 equal dressings per year, resulted in yields of clean seed varying on average from 14 to 28 kg per crop with an apparently linear response. The interpretation of these yields, though low in comparison with those obtained at Kitale, is complicated in that study by the absence of data on PGS percentage, the most unpredictable yield aspect of tropical grasses.

In the late-season crops, a delay of not more than 2 weeks gave the best PGS yields in all 3 experiments of 1970 and 1971. This shows that, although season is important, its effect is reduced if N is applied at an advanced growth stage. Management may have an effect also. In the late-season crops of 1970, yields were highest in Exp. 2 in the harvest, cut and top-dressed on 16 July, and in Exp. 3 in the treatment cut on 13 July and top-dressed on 28 July; the harvest top-dressed on the day after the cleaning cut was high also. Apparently, cleaning cuts earlier or later than mid-July were reducing seed yield.

It is of interest to note that delay in date of cleaning cut or date of top dressing gave similar crop responses. Since treatments had a far more dramatic effect on PGS yield than on head number and 1000-grain weight, seed setting was the component affected most. On the other hand, date of IHE was the same in the early-season crop irrespective of date of top dressing, so that heading and flowering occurred under the same weather conditions whether N had been applied early or not. Consequently, seed setting was determined at some stage before heading, weather conditions during flowering having little, if any, effect on the differences observed.

The obvious importance of applying N to young grass at the onset of the rains can perhaps be explained with some climatic data at hand. Rainfall normally reaches a peak in April-May (Boonman, 1972) and temperatures and solar radiation both drop by about 10 % until they begin rising again after July. Growing conditions may, therefore, be more favourable at the onset of the rains. This is similar to the experience obtained with maize in Western Kenya (Allan, 1972) and other crops in the tropics (MacDonald, 1968). Allan found that each week of delay in maize planting resulted on average in a drop of 650 kg per ha and grain yields were reduced by half if maize planting was delayed 6 weeks.

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Experimental studies on seed production of tropical grasses in Kenya. 6. The effect of harvest date on seed yield in varieties of *Setaria sphacelata*, *Chloris gayana* and *Panicum coloratum*

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Summary

The effect of harvest date was investigated in seed crops of varieties of *Setaria sphacelata* (Nandi), *Chloris gayana* (Rhodes grass) and *Panicum coloratum* (Coloured Guinea) over four years from 1968-1971. Harvest date did not appear to be very critical; it could generally be spread over a period of 1 - 2 weeks. The interval between initial heading and optimum harvest date was normally 6 - 7 weeks. In most crops it was observed that considerable shedding of spikelets could be tolerated before yields of PGS (Pure Germinating Seed) dropped with subsequently delayed harvest dates. As much as 30-50% shedding could be tolerated in Coloured Guinea but usually less than that in Nandi and Rhodes grass. It is suggested that most of the early shedding concerned empty spikelets.

Early heading varieties produced nearly twice as much seed as late heading ones.

Introduction

In seed crops prone to shedding, yields are often sensitive to harvest date (Evers and Sonneveld, 1956; Griffiths et al., 1967). Evans (1966) found that seed losses in ryegrass and cocksfoot were as high as 40-50% when harvesting was carried out 4 days after the optimum date. Shedding is also prevalent in tropical grasses. The picture is further complicated by the wide variety in age of heads and spikelets within heads due to lack of uniformity in heading and flowering (Boonman, 1971a).

In Kenya seed is usually harvested by hand; heads are reaped with sickles and stooked in the field to mature. After a fortnight, seed can be beaten out readily with sticks. Unlike temperate grasses and cereals, tropical grasses are invariably still green at seed harvest.

The present study was prompted by the anxiety among seed growers that the margin between under- and over-ripeness is very narrow. Poor yields are often attributed to having harvested at the wrong time. Traditionally, growers were advised to harvest at the first sign of shedding but this recommendation does not appear to have been based on critical investigation. Hence, it appears imperative to determine how critical the timing of harvesting is and how this can be recognized in the field.

The experiments described below ran concurrently with those on tillering and heading previously reported (Boonman, 1971b). The treatments consisted of different harvest dates. Of each harvest date, yield of clean seed and percentage Pure Germinating Seed (PGS) were measured to calculate the yield of PGS. Observations were also taken on 1000-grain weight of the clean seed and on the percentage of shedding at each harvest date.

Materials and methods

The experimental lay-out has been described in a previous paper (Boonman, 1971b). The varieties were *Setaria sphacelata* cv. Nandi I and Nandi III; *Chloris gayana* cv. Mbarara, Masaba and Pokot Rhodes; *Panicum coloratum* cv. Solai, usually referred to as Coloured Guinea. *Panicum maximum* and *Brachiaria ruziziensis* are of minor importance as seed crops and are not considered in this study.

The first harvest was invariably taken 3 or 4 weeks after Initial Head Emergence (IHE, 5-10 heads per m^2). Subsequent harvests followed at the intervals shown in Table 1.

The interval between harvests was shortened in 1970 and again in 1971 to define the effect of harvest date more precisely. In both years, 2 crops were allowed to develop to conform with commercial practice.

A total of 1212 plots were handled in this study. The usual hand methods of harvesting were followed. At each harvest date 25 random, fully emerged heads were rated visually for percentage shedding of spikelets. Each treatment was subjected to germination tests.

Table 1. Harvesting schedule.

Year	Interval between harvests (weeks)	Number of harvests	Period of optimum harvest dates
1968	2	5	Sept. - Oct.
1969	2	5	August
1970 early - season	1	5	June - July
1970 late - season	1	5	Oct. - Dec.
1971 early - season	½	10	July - August
1971 late - season	½	10	Nov. - Jan. 1972

Results

To simplify the presentation of the data accumulated over 6 seasons of 6 varieties, a summary of the essential data of all 36 crops is given in Table 3. In Table 2 a more detailed account is given of 6 crops, i.e. of 3 different seasons of one variety (Nandi I) and of 3 varieties in one season (early 1971). Fig. 1 presents a picture of how yield of clean seed and PGS, and percentage of PGS and shedding varied, on average, according to date of harvest. Fig. 1 is typical of what was found in nearly all crops: optimum harvest date (OHD) for yield of clean seed was reached before the OHD of PGS yield and shedding affected yield of clean seed more than yield of PGS, as will be elucidated below.

It is evident from Table 2 that harvest date had a profound effect on all yield aspects under investigation. The most important of these is the yield of PGS (yield of clean seed × % PGS = yield of PGS). Yields reached a maximum at a certain date, the optimum harvest date (OHD), but statistical analysis revealed that nearby harvest dates were often not significantly lower in yield than OHD. For instance, in the Nandi I crop of 1969

Table 2. The effect of harvest date on aspects of seed yield.

	Harvest date (weeks after IHE)																			LSD	
	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12	P < 0.05	P < 0.01
Nandi I, 1969																					
Yield of clean seed (kg/ha)			88				108				80				69				54		
PGS (%)			4				9				14				17				13		
Yield of PGS (kg/ha)			3				10a				11a				12a				7a	5	7
1000-grain weight (mg)			520				570				550				600				630		
Nandi I, late 1970																					
Yield of clean seed (kg/ha)			173		123		83		55		23										
PGS (%)			5		15		13		12		21										
Yield of PGS (kg/ha)			9		18		11		7		5									4	6
1000-grain weight (mg)			260		290		350		350		370										
Shed spikelets (%)			0		10		40		70		90										
Nandi I, early 1971																					
Yield of clean seed (kg/ha)		29	39	44	132	105	125	144	129	130	128										
PGS (%)		0	3	11	10	42	40	53	53	58	48										
Yield of PGS (kg/ha)		0	1	5	13	44	50	76b	68b	75b	61									12	16
1000-grain weight (mg)		270	290	320	320	500	480	520	520	490	490										
Shed spikelets (%)		0	0	0	0	10	30	40	40	50	40										
Mbarara Rhodes, early 1971																					
Yield of clean seed (kg/ha)		93	48	50	77	104	143	109	73	88	71										
PGS (%)		3	9	13	32	39	32	45	46	51	54										
Yield of PGS (kg/ha)		3	4	7	25	41c	46c	49c	34c	45c	38c									17	24
1000-grain weight (mg)		240	220	240	260	270	260	270	270	250	260										
Shed spikelets (%)		0	0	0	0	10	30	20	70	50	60										
Coloured Guinea, early 1971																					
Yield of clean seed (kg/ha)		107	111	149	162	142	209	137	120	111	107										
PGS (%)		0	2	7	9	20	12	28	52	44	40										
Yield of PGS (kg/ha)		0	2	10	15	28	25	38	62d	49d	43d									20	28
1000-grain weight (mg)		330	330	370	380	500	410	530	560	560	600										
Shed spikelets (%)		0	0	0	0	10	30	40	50	75	75										

PGS-yields followed by the same letter do not differ significantly at $P < 0.05$.

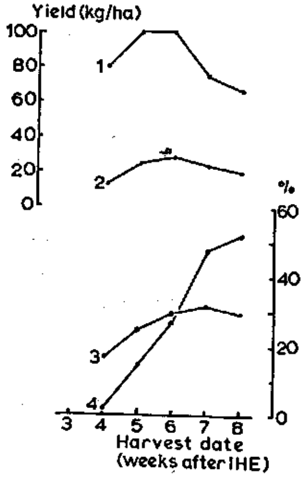

Fig. 1. The average effect of harvest date on yield and shedding. 1 = yield of clean seed; 2 = yield of PGS; 3 = % PGS; 4 = % shedding.

yields were highest at the 10th week (W_{10}) but those at W_6, W_8 and W_{12} were not significantly lower at $P < 0.05$. Consequently, any harvest date from 6 - 12 weeks after IHE was appropriate to achieve maximum yield. In other words, harvesting could be carried out over a safety range or margin of 6 weeks. In contrast, the Nandi I crop of late 1970 had no such margin. It showed a critical OHD at W_5, with significantly lower yields at W_4 and W_6. Of the early 1971 crops, Nandi I, Mbarara Rhodes and Coloured Guinea gave harvest margins of 1 week ($W_{6½}$ - $W_{7½}$), 2½ weeks ($W_{5½}$ - W_8) and 1 week (W_7 - W_8), respectively. Obviously, these safety ranges were even wider at $P < 0.01$.

The OHD and harvest margins of all 36 crops, together with the corresponding data on PGS yields, 1000-grain weights and shedding are presented in Table 3. Yield of PGS (a) and 1000-grain weight (d) are given for the optimum harvest date (b) only, while (c) indicates the range, if any, of harvest dates on which PGS yields were not significantly lower than at (b). Under (e) the percentage of spikelet shedding is given for the last date of (c) or, where no range was present, for OHD.

It can be seen from Table 3 that OHD varied according to season and, to a lesser extent, according to variety. In more than 70% of all 36 crops, OHD occurred at W_5, W_6 or W_7, with an overall average of 6.6 weeks after IHE. The crops of 1969 and late 1971 were clear exceptions, with intervals between IHE and OHD of, on average, 8.8 and 4.8 weeks, respectively. This was most likely due to climatic reasons. The early-season crops normally mature in June or July and the late-season crops in October or November. Table 4 presents the long-term climatic data for these periods. The crops of 1969 and late 1971 were harvested in unusual months (Table 1), with different weather in the period of heading and maturation (Table 4). The 1969 crop matured in weather with more rain and fewer hours of sunshine than normal, whereas the crop of late 1971 had less rain and more hours of sunshine than the usual harvest months. This would suggest that the interval between IHE and OHD is reduced in bright, dry weather. However, more data on unusual harvest periods are needed to verify this theory, since the above trend was not consistent in all seasons of this study.

Varieties differed little in OHD, largely irrespective of whether they were early or late heading. The only consistent difference observed was that the late heading Pokot Rhodes (Boonman, 1971b) was never later in OHD than Masaba Rhodes.

Table 3. The effect of harvest date on:
(a) yield of pure Germinating Seed (kg/ha) at (b);
(b) optimum harvest date (weeks after Initial Head Emergence);
(c) range of weeks of harvests with yields not significantly lower than at (b);
(d) 1000-grain weight (mg) at (b);
(e) percentage of spikelets shedding at last date of (c), or at (b).

Variety		Year/season						
		1968	1969	early 1970	late 1970	early 1971	late 1971	Mean
	Interval between harvests (weeks)	2	2	1	1	½	½	
Nandi I	(a)	24	12	9	18	76	50	32
	(b)	6	10	5	5	6	4½	6.1
	(c)	6-6	6-12	4-5	5-5	6-7	4-4½	1.4*
	(d)	330	600	290	290	520	500	420
	(e)	10	NR	10	10	60	10	20
Nandi III	(a)	5	12	4	12	35	19	15
	(b)	7	8	6	6	6	6	6.5
	(c)	5-9	8-8	3-9	5-6	4½-6	4-7	2.6
	(d)	330	570	280	330	490	500	420
	(e)	10	NR	60	20	20	30	30
Mbarara Rhodes	(a)	56	15	32	40	49	73	44
	(b)	8	11	5	6	6	4	6.7
	(c)	6-8	5-11	5-5	6-9	5-7½	3½-6	2.7
	(d)	340	270	240	260	270	290	280
	(e)	20	NR	10	60	50	50	40
Masaba Rhodes	(a)	68	10	12	84	32	36	40
	(b)	6	10	8	7	7½	5½	7.3
	(c)	6-6	4-10	8-8	6-8	5-7½	4-6	2.1
	(d)	320	280	200	270	240	270	260
	(e)	0	NR	40	60	30	10	30
Pokot Rhodes	(a)	53	6	11	48	12	13	24
	(b)	6	6	7	6½	7½	3	6.0
	(c)	6-6	4-10	7-7	5-7	6-8½	3-4	1.9
	(d)	370	320	250	330	290	310	310
	(e)	30	NR	30	40	60	NR	40
Coloured Guinea	(a)	46	46	78	30	62	51	52
	(b)	8	8	6	7	6½	5½	6.8
	(c)	8-12	8-10	6-6	6-7	6½-7½	4½-6	1.6
	(d)	390	380	500	420	560	530	460
	(e)	30	NR	50	40	70	50	50
Mean	(b)	6.8	8.8	6.2	6.3	6.6	4.8	6.6
	(c)	1.7	4.3	1.2	1.5	1.8	1.8	2.1*
	(e)	20	NR	30	40	50	30	30

* Means denote average length of range in weeks.
NR = not recorded.

Table 4. A climatic comparison of seed maturation periods.

	Monthly rainfall (mm)	Days with more than 1 mm rain	Daily hours of sunshine	Mean daily temperature (°C)
July - August 1969	139	18	6.7	17.3
June - July (long-term)	123	16	6.9	17.5
November - December 1971	58	8	7.5	17.5
October - November (long-term)	89	13	6.9	18.1

Table 3 also indicates that the safety margin of harvest dates was fairly wide in most crops. About 50% of all 36 crops had a margin of 2 weeks or more, 75% had 1 week or more, and in only 25% of the crops OHD was critical. On average, a margin of 2.1 weeks was observed, calculated on the basis of $P < 0.05$; at $P < 0.01$ this was increased to even 2.4 weeks (data not presented). The 1969 crops were again exceptional. The margin amounted to as much as 6 weeks in 4 of the 6 varieties. Compared with other seasons, this could not be attributed to weather, yield level, harvest interval or experimental error. Seasons and varieties alike, there were no significant correlations between PGS yield at OHD, interval between IHE and OHD, and harvest margin, so that all varied independently.

At each harvest date, 25 randomly collected heads were rated visually on a 1-5 scale and percentage of shedding of spikelets was calculated. Fig. 1 and Table 2 show that the percentage of shedding increased rapidly as harvest was delayed, normally starting 4-5 weeks after IHE. The shedding characteristics of all crops are given in Table 3. To indicate how much shedding can be tolerated before PGS yields drop with further delayed harvesting, shedding percentages are given only for the last date of the safe harvest range or for OHD where no range occurred. At these dates, most crops tolerated considerable shedding which seemed to vary according to species. Coloured Guinea tolerated more shedding than Rhodes grass and Nandi.

As the percentage of shedding increased yield of clean seed reached its maximum soon in contrast with the percentage of PGS which continued to increase for a longer period (Fig. 1, Table 2). It was not until 40-50% shedding occurred that the percentage of PGS reached a maximum. Fig. 2 shows the relation between shedding and PGS yield as derived from Fig. 1. Yield of PGS increased until some 25% of the spikelets had shed and decreased beyond that point.

The relationship between OHD for yield of clean seed and OHD for percentage PGS

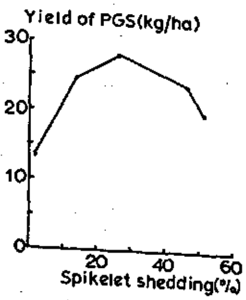

Fig. 2. The effect of shedding on the yield of PGS.

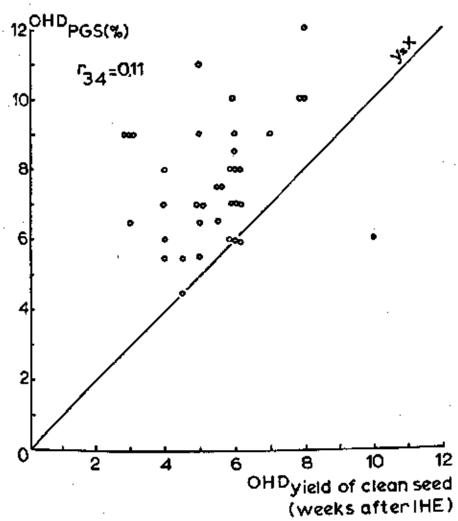

Fig. 3. The relation between optimum harvest date (OHD) for yield of clean seed and percentage PGS.

of all crops is borne out in Fig. 3. The maximum percentage PGS was clearly reached at a later date than maximum yield of clean seed, the difference being on average some 2 weeks. Only one crop was situated below the 45° line. In a generalized sense, the following chronological sequence prevailed:

$$OHD_{\text{Yield of clean seed}} \xrightarrow[\text{1 week}]{} OHD_{\text{Yield of PGS}} \xrightarrow[\text{1 week}]{} OHD_{\text{PGS (\%)}}$$

It is evident that seed maturation was better at more advanced harvest dates. The data on 1000-grain weight lend support to this contention (Table 2, Fig. 4). Except in Rhodes grass, 1000-grain weight increased markedly with delayed harvest date.

The 1000-grain weight also varied according to season and variety (Table 3). In Coloured

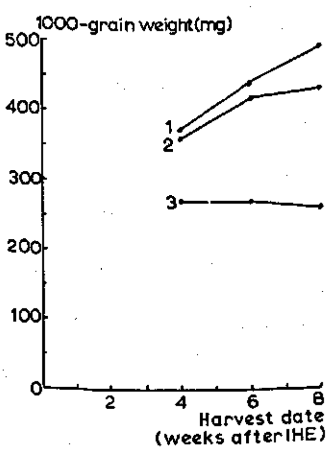

Fig. 4. The average effect of harvest date on 1000-grain weight. 1 = Coloured Guinea; 2 = Nandi I; 3 = Mbarara Rhodes.

Guinea and both Nandi varieties, weights were highest in 1969 and 1971, years with low and high yields, respectively. In Rhodes grass weights were highest in 1968, the establishment year. Coloured Guinea tended to produce the heaviest seed of all varieties, followed by Nandi and, finally, Rhodes grass. At the varietal level, Pokot produced heavier seed than Mbarara and Masaba Rhodes.

The PGS yields presented in Table 3 give a good comparison of the yielding ability of the different varieties, since they all refer to the optimum harvest date. Nandi I produced more than twice the amount of Nandi III; Mbarara produced nearly twice as much as Pokot Rhodes. The early species Coloured Guinea was the best overall. Consequently, the highest yields were produced by the early heading varieties. Yields varied considerably according to season and a strong variety × season interaction was apparent.

Discussion

Harvest date was critical in only a quarter of all 36 crops investigated in this study. In half of the crops, harvesting could be carried out safely over a range of dates covering 2 weeks or more. In 75% of the crops this safety margin was more than 1 week. It can therefore be concluded that harvest date is not very critical in the tropical grasses of this study. This finding is of practical importance because it means that the seed grower can confidently and conveniently determine when to harvest.

There was no indication that the rapid heading varieties, Coloured Guinea and Mbarara Rhodes (Boonman, 1971b) had narrower margins than other varieties. The data on heading for the 1970 and 1971 crops (data not presented) confirmed the earlier finding (Boonman, 1971b) that OHD was reached long before head numbers reached their maximum. After IHE, head numbers increased at an almost constant rate until a stage beyond that of OHD. This extended heading, together with the prolonged flowering within heads (Boonman, 1971a) is the explanation for the occurrence of a 1 - 2 week safety margin in harvesting. Flowering is reduced in late-emerging heads (Boonman, 1971a); otherwise, an even wider margin might have been expected. In temperate grasses Evans (1966) also found that harvest date was less critical if flowering was prolonged.

In an experiment on *Setaria sphacelata*, involving various varieties, nitrogen levels, row widths and harvest dates, Hacker and Jones (1971) also found no differences in yield of clean seed between harvest dates covering a 2-week period. This only applied, however, if yields were averaged over the 5 seasons of that study. Within seasons, yields varied significantly with harvest date but the rankings were not consistent over the seasons. This experiment differed from the one before us in that no practical harvest or ripeness indicators were used, which are needed to ensure the repeatibility of harvest dates in this type of experiments. Moreover, yield of clean seed is no adequate yield determinant because of its low correlation with percentage PGS (Fig. 1, Table 2, Fig. 3).

Date of IHE is important as base date for the timing of harvest dates in each season and can, together with the percentage of shedding, be used as a practical ripeness indicator. The interval between IHE and OHD was normally about 6 - 7 weeks (Table 3), so that IHE is a useful guide to predict the approximate date of harvest. More evidence is required to confirm the trend observed in Table 4 that the interval between IHE and OHD is affected by the weather prevailing during heading and seed maturation.

Shedding is also an important ripeness indicator. In former practice, the recommended harvest date was at the first sign of shedding but this is obviously too early. A considerable amount of shedding can be tolerated before PGS yields drop (Table 3). In Coloured Guinea, PGS yields were not affected until 30-50 or more percent of the spikelets had shed. Rhodes grass and Nandi were more sensitive to shedding than Coloured Guinea, yet their tolerance was still high.

The large amount of shedding that can apparently be tolerated without impairing PGS yields (Fig. 2), raises the question whether the early shed seed does indeed consist of properly developed spikelets. Naturally, as harvesting is delayed shedding, in absolute sense, increases and the losses incurred may be off-set by an accompanying gain of new seed in late maturing heads and spikelets. This complication was avoided in this study by determining the percentage shedding in a randomly harvested sample, containing old and newly emerged heads. Yet, percentage shedding increased rapidly as heading proceeded. Mwakha (1970) suggested that in *Entolasia imbricata* unfertilized spikelets absciss early, while fertilized ones only absciss on ripening. Circumstantial evidence suggests that most of the early shedding in the material of the present study also concerned empty spikelets:

a. OHD of yield of clean seed preceded OHD of percentage PGS and yield of PGS by on average 2 and 1 week, respectively. Consequently, yields of clean seed could well drop, through shedding, while PGS yields were still on the increase, apparently because full spikelets were retained (Fig. 1, Fig. 3).

b. The 1000-grain weight of harvested, clean seed increased with delayed harvest date in Nandi and Coloured Guinea, though not in Rhodes grass (Table 2, Fig. 4).

c. Some 3 to 4 months after IHE, shedding is normally complete even in the late emerged heads. It was shown earlier (Boonman, 1971a) that flowering is very much reduced in late-emerging heads so that seed setting is likely to be minimal. Hence, if the premature shedding in the late emerged heads is due to bad seed setting, the same principle will apply to other circumstances of bad seed setting.

Gordin-Sharir and Gelmond (1966) also concluded that cutting Rhodes grass too early resulted in a high percentage of empty spikelets.

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Experimental studies on seed production of tropical grasses in Kenya. 7. The breeding for improved seed and herbage productivity

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Summary

The history and characteristics of the Kitale grass varieties and the practices of seed multiplication are described.

Spaced-plant populations of various varieties of *Setaria sphacelata* and *Chloris gayana* were studied with a view to selecting suitable plants for developing varieties with better seed and herbage productivity. It was observed that these populations were heterogeneous in heading time, growth habit and vigour, and head number per plant. In most varieties there were 5 - 6 weeks between the dates of the first and the last 5% of the plants to head. Heading time was largely determined by vigour. The more vigorous the plants, the earlier they began heading. More heads were found in the early-heading plants.

In 18 clones, grouped together on the basis of even and early heading, good vigour and high head number, great variation was observed in the yield of Pure Germinating Seed (PGS) per plant, head number and seed setting per plant. Three outstanding clones had average PGS yields three times as high as the average of all 18 clones. Heritability for PGS yield and its components was invariably high.

It is concluded that breeding should have the following major objectives: even heading date, good plant vigour, potentially high head number, high seed setting, persistence and high nutritive value.

Introduction

There can be little doubt that the seed yield responses to the management factors described in the previous papers of this series were limited by the genetic make-up of the current Kitale varieties. It was shown that both intraplant and interplant heading are spread over so many weeks that shedding is commonly observed long before head emergence is completed. Similarly, flowering and shedding can occur simultaneously within single heads (Boonman, 1971a, 1971b). Seeds shed readily but the shedding and flowering of spikelets depend largely on the history of the heads they are on. Hence, heading patterns are of overriding importance.

Griffiths (1965) has summarized literature on selection for seed production in grasses. He concluded that such selection could be carried out successfully without prejudice to herbage productivity.

To achieve real progress by breeding it is imperative to know the characteristics of the varieties already in use. Of equal importance is a sound practical appreciation of the type of grass required in future.

The history of the present Kitale varieties and their multiplication

Most of the early work has been documented by Bogdan (1959, 1965, 1966) and it suffices here to mention the main events and the developments after 1966.

Out of some 4000 introductions collected from eastern Africa and elsewhere two superior species emerged: *Chloris gayana* (Rhodes grass) and *Setaria sphacelata*. The Nandi ecotype of *S. sphacelata* was introduced by D. C. Edwards as far back as 1935 while the Masaba and Mbarara ecotypes of *C. gayana* were introduced in the 1950's by R.Strange and A. V. Bogdan. These three varieties, all early heading and released without individual plant selection, quickly replaced the old farmers' varieties such as Nzoia Rhodes and Molasses grass and have had a great impact on ley farming in Kenya. In the early 1960's, individual plant selection led to the development of Pokot Rhodes, a late-heading variety. A late-heading Nandi II was developed through mass selection from the original Nandi variety, subsequently renamed Nandi I (Bogdan, 1965). Out of Nandi II, an even later heading variety was developed, Nandi III, through family selection. The view was held that early-heading varieties were necessarily stemmy and of inferior nutritive value. As a result, the planting of new multiplication fields of Nandi I was discontinued in 1967 and the same was about to happen with Mbarara Rhodes, so that late-heading varieties would have remained only.

The primary objective of the early work at Kitale was to multiply promising material quickly, and tribute must be paid to A. V. Bogdan and R. Strange for their effort. Demand for seed of the new varieties was understandably high. Consequently, efforts were directed to the rapid building up of seed stocks, but little attention was paid to maintaining material close to its original constitution. Varieties were multiplied from generation to generation and seed issues were made to the seed industry for further bulking and trade. In the process of multiplication attention was confined to isolation and weeds.

When evidence became available that this system of continuous multiplication led to considerable shift the decision was taken to stabilize the current varieties (Boonman, 1971a). Spaced-plant populations were established from which subsequent multiplications were to originate. In 1968 and 1969 plants were collected at random from multiplication fields of known name and history. Some 4000 plants for Nandi I and Nandi II, and 1000 each for the other tufted grasses, *Panicum coloratum* cv. Solai, *Panicum maximum* cv. Makueni and *Brachiaria ruziziensis*, were planted 1 m apart. Of the 3 Rhodes grass varieties, Mbarara, Masaba and Pokot, 1000 plants of each were set out 4 m apart so that each plant could form a little sward. Varieties were grown in isolation and the seed harvested was issued to a local seed company for further multiplication under official certification. This superseded the previous system of uncontrolled multiplication, from 1970 onwards.

In these spaced-plant populations considerable plant-to-plant variability was subsequently noticed in major characters such as heading date, vigour and general plant type. This offered an opportunity to start a breeding programme on the basis of intravarietal variation.

Characteristics of present Kitale varieties

The evidence now available on existing varieties offers some help in defining the breeding objectives for future varieties. Table 1 summarizes the main features, assembled together from published (Boonman, 1971b, 1973) and unpublished data.

The Guinea grasses are the first to head but they are low in herbage yields. Coloured Guinea, however, produces the highest PGS yields of all grasses, whereas Makueni is

Table 1. The major characteristics of Kitale varieties (after Boonman, 1971b, 1972c and unpublished data).

	Sequence in week of Initial Head Emergence (IHE)	Number of tillers at IHE per m²	Weight per tiller at IHE (mg)	Yield of dry matter (tons/ha), 8 weeks after cleaning cut	Yield of dry matter (tons/ha) at advanced heading	Maximum head number per m²	Maximum percentage heading tillers	Culm length at optimum seed harvest (cm)	1000-grain weight (mg) at optimum seed harvest	PGS-yield per crop (kg/ha) at optimum seed harvest
	1968-1971	1969	1969	1969	1969	1969	1969	1969	1968-1971	1968-1971
Setaria sphacelata cv. Nandi I	3	950	260	6.0	8.1	350	25	150	420	32
Setaria sphacelata cv. Nandi II	4-5									22
Setaria sphacelata cv. Nandi III	5-6	980	220	5.0	7.7	170	9	135	420	15
Chloris gayana cv. Mbarara	2	1550	210	7.0	7.7	320	20	132	280	44
Chloris gayana cv. Masaba	4-5	1290	190	6.3	7.1	230	13	130	260	40
Chloris gayana cv. Pokot	6	1260	260	5.7	7.5	160	12	130	310	24
Panicum coloratum cv. Solai	1	1530	200	4.0	7.1	520	34	115	460	52
Panicum maximum cv. Makueni	1	1150	280	4.2	4.9	130	10	144	540	25
Brachiaria ruziziensis (Congo Signal)	9	1240	280	5.0	7.4	470	37	126	1930	23

relatively low. Congo Signal *(Brachiaria ruziziensis)* is an extremely late-heading variety and only produces one seed crop a year, of rather low yield. In spite of its high percentage of heading tillers, Coloured Guinea is persistent in leys, in contrast with Makueni and Congo Signal, under Kitale conditions. These three species are not widely used in Kenya. Most of the seed grown of Makueni and Congo Signal is exported to other countries where they are reported to be doing well under warmer conditions.

As noted earlier, the species receiving most attention at Kitale are Rhodes grass and setaria. Broadly speaking, Rhodes grass varieties are popular with the average farmer because of their ease of management and wide adaptation, whereas more sophisticated farmers in the medium altitudes (above 1700 m) tend to favour Nandi, which is more persistent. It is evident from Table 1 that the early-heading varieties excel in both herbage and seed yield. The PGS yields of the early-heading varieties are nearly twice as high, although Masaba Rhodes, a medium-early variety, produces almost as much as Mbarara Rhodes.

Varieties can be distinguished on the basis of tiller numbers and weights at Initial Head Emergence (IHE, 5-10 heads per m^2). In Rhodes, the late-heading Pokot has fewer but heavier tillers and produces heavier seeds. The late-heading Nandi III, however, has more and finer tillers and shorter culms than Nandi I.

No exactly comparable data for Nandi II are available. In view of the breeding history outlined above, it can be assumed that the characteristics of Nandi II are intermediate between those of Nandi I and Nandi III. If data from comparable trials and seasons are used, the estimated PGS yield of Nandi II can be put at 22 kg (Table 1). Data collected on PGS yields obtained from commercial fields grown at the National Agricultural Research Station in Kitale between 1964 and 1968, the period when all three varieties were in production, showed that the average annual yields of PGS were 30, 18 and 12, respectively, which correspond well with the yields given in Table 1. The important conclusion arises that PGS yield is increased by about 50% from Nandi III to Nandi II and again from Nandi II to Nandi I, with increased earliness.

Breeding objectives

Clearly defined objectives and the correct choice of source material are of paramount importance in a breeding programme. The basic aim is to improve both the seed and herbage productivity, including nutritive value, of the existing Kitale varieties.

The major objectives are to include (1) high seed yield and (2) long-lasting (persistent) and well-distributed production of a large quantity of nutritious herbage. In view of the scope of the present series of studies, priority is here given to breeding for seed yield, but it is essential to know how this affects herbage characteristics. Information is needed to see if simultaneous improvement is feasible.

Close matching of the basic clones as regards heading date is a prerequisite not only to attain maximum seed yield but also to guarantee proper interplant fertilization and to prevent shift in subsequent cycles of multiplication. A bred variety must be sufficiently uniform for authenticity and stability.

To improve seed yield further, there are various breeding possibilities, such as increasing head number, seed setting or seed weight on the one hand, or improving the efficiency of components to bring about more even maturation on the other.

For herbage breeding, persistence and a good seasonal distribution of production are important. In mixed-farming areas where cereals and short-term leys alternate, persistence is less of a problem. In milk-economy areas, however, farmers are tending to specialize more and more in dairy production and going out of cereal production. These farmers need persistent grasses. Good seasonal distribution of growth is difficult to tackle from the breeding side. Growth rate is highest at the onset of the rains (Boonman, 1972c) and lowest in the dry season. Management is the best way for the farmer to reconcile the fluctuations in supply and demand. Conservation of surplus growth in the form of hay or silage is becoming popular, as this enables farmers to bridge the gap in the dry season without having to devote extra land to the growing of special fodder crops. Irrigation, already practiced in some areas, will become more widespread. In many areas of Kenya, and elsewhere in the tropics, stocking rates are high in relation to grass growth, even in the rainy season. To date, no compatible, productive legume is available and the reliance on nitrogenous fertilizer is steadily increasing, helped by the favourable ratio of milk/nitrogen prices.

Under good growing conditions, Kitale grasses are capable of achieving high dry matter yields. Growth rates of over 140 kg DM ha^{-1} day^{-1} were reported (Boonman, 1971b). In contrast nutritive value, measured in terms of digestibility, is low. Breeding for higher nutritive value is therefore essential and could be conducted along two lines: (1) to obtain a higher digestibility at a given yield capacity and (2) to improve the yield capacity, i.e. vigour of (re)growth which would enable the farmer to graze more often at a desirable level of digestibility.

The studies reported here were carried out to examine the material available in the spaced-plant populations referred to above. In view of the past experience with breeding it was thought necessary to examine some parameters and their relationships before defining a breeding policy.

Phenotypic selection is commonly used to reduce large source populations to manageable sizes. At this stage a distinction is made between what is believed to be good or bad and the ultimate success of the breeding programme depends on the correctness of this decision. It is therefore of paramount importance to have a good knowledge of the material that is to be carried forward.

Materials and methods

After preliminary observations in 1969 and 1970 more detailed studies were made in 1971 as follows.

Setaria sphacelata

The spaced-plant populations of Nandi and Nandi II, each consisting of over 4000 plants planted 1 m apart, were allowed to develop two consecutive seed crops in 1971 and observations were taken as follows:

– week of heading (W_1): the week in which the plant had developed 10 fully emerged heads, W_1 being the week when the first 1 - 5% of all plants had 10 heads;

– growth habit: at W_1 all plants were classified as tall, short or poor;

– vigour: plants were ranked on a 1 - 5 scale for vigour of regrowth 1 month after the cleaning cut, where 5 represents the greatest vigour; this observation, ancillary to that of growth habit, was carried out in the late-season crop;

– head number, shedding, lodging and diseases.

In August 1971, 18 Nandi plants were selected on the basis of early heading, even heading date, adequate head production and tall growth habit. They were subsequently planted out in clones of 4 replicates, at a spacing of 75 × 50 cm. This made it possible to estimate genotypic variances and heritabilities for seeding properties.

The spaced-plant populations of Mbarara, Masaba and Pokot Rhodes, each consisting of about 1000 plants set out 4 m apart with paths between the plots, were allowed to develop two consecutive seed crops in 1971 and observations were taken as follows:
- week of heading: when heads began emerging evenly over the whole plot;
- vigour: when 1 - 5% of the plants had reached W_1, all plants were ranked on a 1 - 5 scale for vigour of regrowth;
- head number, shedding, lodging and diseases.

In all above plant evaluations about 100 kg N $ha^{-1}crop^{-1}$ was applied as a top dressing.

Results

The relationship between growth habit and week of heading in Nandi is borne out in Fig. 1. The proportions of tall, short and poor plants are shown for each heading week.

As heading week proceeded tall plants decreased whereas poor plants increased as a percentage. The highest percentage of short plants was observed at W_4. W_8 consisted almost entirely of poor plants. Consequently, early heading was closely associated with tall plants. Although Fig. 1 refers to the first crop of Nandi I of 1971 only, the same was confirmed for consecutive crops, also those of Nandi II.* The latter contained more short plants, fewer poor plants and appeared to be more uniform than Nandi I. In the Rhodes grass varieties, a predominant proportion of plants in the early-heading groups grew erect after planting and it took them a longer time to cover a given area with stolons (data not presented).

Classifying Nandi plants for growth habit may be more suited to the later stages of a selection programme, but in the early stage with its great variability it was found easier to rank individual plants on a 1 - 5 scale for vigour of regrowth.

An important finding corroborating the evidence presented in Fig. 1 is that both in Nandi and in Rhodes grass heading week was negatively correlated with vigour (Table 2).

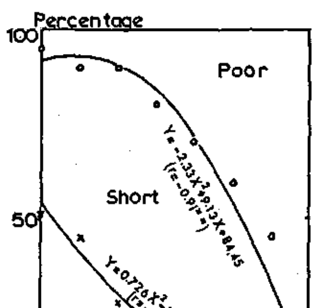

Fig. 1. Relationship between growth habit and week of heading.

* To pool the data of all crops and varieties formulas were devised which will be published elsewhere.

Table 2. Correlation coefficients between heading week and vigour (varieties pooled per species).

	df	r	P
Nandi	4244	–0.14	0.01
Rhodes	5559	–0.12	0.01

Thus the more vigorous a plant the earlier it heads. Late-heading, vigorous plants do occur but there are very few.

The heading patterns of the spaced-plant populations of Nandi I, Nandi II, Mbarara, Masaba and Pokot Rhodes are shown in Fig. 2. The interval between the dates of the first and the last 5% of the plants to come into head varied from 4 weeks in Mbarara and Nandi II to 6 weeks in Masaba and Pokot.

The herbage was usually cut back at W_9 or W_{10}, when over 99% of the plants had commenced heading. At this time plants were observed for head number. Early-heading plants were naturally at a disadvantage because many had collapsed by then. Nevertheless, it was found in Nandi that plants with many heads were more frequent within the group of tall plants (Table 3).

In 85 unreplicated plants of the spaced-plant population of Nandi II, heads were counted weekly in three consecutive seasons. One plant failed to produce heads at all. Only 15 plants produced more than 200 heads in all three seasons. Some of these produced this number more rapidly than others. Nearly all plants with many heads belonged to the early-heading groups, even though later-heading plants had had ample time to show this character.

An additional positive feature of early heading was its apparent correlation with drought tolerance. The Nandi I crop produced some vigorous plants with many heads in March 1972, even though this was right at the end of a severe dry season. It was subsequently found that 75% of these plants were those which had belonged to W_1 and W_2 in the first crop of 1971. This suggests that early, vigorous plants were also more drought-tolerant

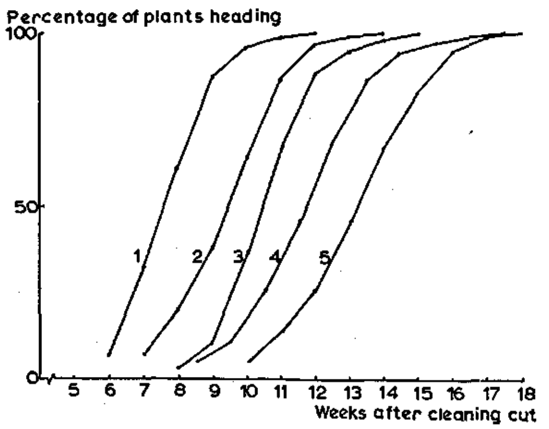

Fig. 2. Heading patterns in spaced-plant populations of Nandi and Rhodes varieties; averages over 3 seasons.
1 = Mbarara Rhodes; 2 = Nandi I; 3 = Nandi II; 4 = Masaba Rhodes; 5 = Pokot Rhodes.

Table 3. Percentage per growth habit (Nandi I, early-season crop).

	Growth habit		
	tall	short	poor
In original population	28	49	23
In plants with many heads (20% of original population)	40	51	9

Table 4. Correlation for heading week and vigour over two consecutive crops (varieties pooled per species).

	df	r	P
Heading week			
Nandi	2038	0.41	0.01
Rhodes	2908	0.63	0.01
Vigour			
Nandi	1033	0.40	0.01
Rhodes	2828	0.30	0.01

probably because they had formed more regrowth when the dry season began.

If selection is envisaged, heading date and vigour must be consistent over consecutive seasons. Table 4 shows that the correlation coefficients were highly significant, indicating that there was good consistency.

Seeding properties of some selected Nandi clones

The characteristics of 18 clones which had been selected from the Nandi populations on the basis of early and even heading date, adequate head production and tall growth habit, are presented in Table 5.

The mean of all 18 clones is compared with the mean of the group of 3 outstanding clones which differed significantly from subsequently ranked clones. The values of heritability (clones) are given, which when multiplied by the selection differential give an estimate of the genetic gain obtained in the top group of 3.

It is evident from Table 5 that the genetic gain of + 178% was high for yield of PGS. With the opted selection differential, yield of PGS was increased threefold. This increase was only partly due to the small increase observed in 1000-grain weight. The main yield components causing the said increase were head number and seed setting per head even though heads were shorter in the top group. The degree of shedding was considerably higher in the top group. apparently because they began heading about 1 week earlier. It was suggested in a previous paper, however, that early shedding does not necessarily mean the loss of valuable seed (Boonman, 1973).

As regards the effect of selection for seed yield on herbage properties, it can be seen from Table 5 that the top group was more vigorous both in the first growth and the regrowth. The fresh weight of herbage at seed harvest was not significantly different between clones. Its heritability was low. These findings are hardly surprising because at the advanced stage of seed harvest poor clones have normally caught up with the better ones. The top group was less prone to lodging at seed harvest.

Table 5. The genetic variation in 18 early heading plants of *Setaria sphacelata* cv. Nandi.

	Week of heading (weeks after cleaning cut)	Yield of PGS per plant (g)	PGS* (%)	Yield of clean seed per plant (g)	Head number per m^2	Mean head length (cm)	Number of germinating seeds per head	1000-grain weight (mg)	Fresh weight per plant (kg)	Shedding (1-5) 5 = no shedding	Lodging (1-5) 5 = no lodging	Vigour (1-10)	
												1st growth	regrowth
Mean of 18 clones	7	0.45	27.1	1.66	72	19.7	9.8	520	2.9	4.2	2.9	5	6
Mean of 3 selected clones	6	1.39	49.8	2.79	148	17.8	17.9	540	3.1	3.2	3.2	6	7
Heritability (clones)	0.47	0.85	(0.90)*	0.70	0.87	0.89	0.60	0.72	0.15				
Genetic gain (%)		+178	(+75)*	+48	+92	-8.6	+50	+2.8	+1.0				

* Means of clones based on weighted means; heritability and genetic gain based on straight means.

The above results refer only to one harvest and one location. More information is needed to verify these findings.

Discussion

The wide range in heading date (Fig. 2), the consistency of heading week over consecutive crops (Table 4) and the high heritability for week of heading (Table 5) indicate that considerable improvement in seed yield will result from grouping plants according to date of heading. Further improvement in seed yield can be achieved by utilizing the variation in seed yield components, namely seed weight, seed setting and head number (Table 5). All these characters had a high heritability so that mass selection is an appropriate method to pick out superior genotypes (Latter, 1964). Their responses to various husbandry measures such as fertilizer, planting density and harvesting time have been reported previously (Boonman, 1972a, 1972b, 1972c, 1973).

Differences in 1000-grain weight, though significant, were small. The three best-yielding plants produced a slight genetic gain of only 2.8%, in contrast with the genetic gain of 178% in yield of PGS. Improvement of the seed weight may have more significance if increased seedling vigour is sought than as a tool to increase seed yield, as the advantage of higher weight would be off-set by the need for higher seed rates.

Seed setting, i.e. the number of PGS per head, was observed to vary greatly from plant to plant (Table 5). Seed setting appears to be the single most important yield component requiring the attention of the breeder. It is however the most difficult to determine as it requires laborious testing. High yield of clean seed of clones is normally not accompanied by an equally high percentage germination ($r_{76} = -0.04$). The method in this study was to germinate a sample of the clean seed (Boonman, 1972b). Purity tests, i.e. the separation of full and empty spikelets (Gildenhuys, 1950), may produce quicker results but they give little indication as to whether the pure seed is ultimately going to germinate. Seed setting per head was certainly not positively correlated with head length, as head length was on average shorther in the top group of Table 5.

Seed setting is sometimes reduced by bunt (*Tilletia echinosperma* Ainsworth) in Nandi and *Panicum*. When an epiphytic occurs some plants are less affected than others (Boonman, unpublished data). Behaeghe and Blouard (1962) have shown that breeding for resistance against *Sphacelotheca setariae*, a similar if not the same disease, is possible.

Spikelets normally absciss upon maturation but there are indications that direct selection for better seed retention is feasible. Of specific importance is the need to develop varieties with consistently high seed setting so that the large season-to-season and year-to-year variation in seed yield might be reduced (Boonman, 1972a, 1972c, 1973).

An increase in head number, even more so if more heads are produced in less time, has a direct effect on yield of PGS (Boonman, 1972a). In the present study head numbers were found to vary from nil to over 600 per m^2 at seed harvest in well fertilized Nandi plants. However good the seed setting per head, this must be accompanied by a high number of heads if high PGS yields are to be achieved.

The negative correlation between vigour and heading week (Table 2) lends support to the contention submitted here that plants do not produce heads in any appreciable quantity until a minimum of herbage has accumulated. This is a crucial difference from grasses in temperate climates, where day length is the principal determinant of heading time. Therefore, certain concepts on quantity-quality relationships of herbage developed for temperate grasses do not apply to Nandi or other tropical grasses behaving similarly. In temperate climates, heading is rapid and accompanied by a sharp decline in digestibility In tropical grasses heads do not appear in any number unless a certain amount of vegetative growth has developed. Even then, heading is a gradual process and it takes abou six weeks after IHE until some 200 heads have emerged per m². At this stage it is stil possible to harvest over 50% of the dry matter in the form of non-heading tillers (Boonman, 1971b, 1972a). This may explain Minson's (1971) finding that tropical grasses do not drop in digestibility as rapidly as temperate grasses.

As heading time is largely determined by vigour, selection for numerous heads should not necessarily lower the herbage quality, certainly not in the pre-heading stage. In fact, young stems are of higher digestibility than leaves (Raymond, 1969; Hacker, 1971).

It was pointed out earlier that varieties must consist of plants grouped according to heading time. If this grouping were done without due regard to the negative correlation observed between vigour and heading week (Fig. 1, Table 2) late heading groups would possess reduced vigour. They also produced fewer heads (Table 3) and are therefore likely to produce less seed as was found by Evans et al. (1960) in bred varieties of temperate grasses. Local evidence to support this contention can be seen from Table 1. Nandi II and Nandi III were developed out of Nandi I primarily for late heading (Bogdan, 1966). Nandi I produced not only higher yields of seed, but also of herbage. A recent Australian report (Hacker, 1972) confirmed that Nandi I (Commonwealth Plant Introduction (CPI) 28709) had a higher herbage yield than Nandi II (CPI 32232). At Kitale, Mbarara Rhodes was found to produce higher yields of dry matter and digestible organic matter than Masaba and Pokot Rhodes (Thairu and Sheldrick, unpublished data).

Preliminary evidence (van Wijk, unpublished data) indicates that early-heading varieties of either Nandi or Rhodes grass have similar if not higher in-vitro digestibilities than late-heading varieties, at a given time, let alone at heading date or at a given level of yield. Additionally, early-heading varieties appear to be more persistent under grazing than late-heading varieties (Boonman, unpublished data). Consequently, late-heading varieties have little to commend them. Varieties that do not run to head early may, however, have a role to play in systems of extensive grassland use, but it is then still important to have late heading combined with high vigour. Even in the very late-heading groups a small proportion of vigorous plants occurs (Fig. 1). However, it requires more effort to pick them out. More difficult may be the task of combining late heading with good seed yield. Masaba Rhodes is, however, an example of a variety that is a good seed yielder though not early-heading (Table 1).

Preliminary evidence (van Wijk, unpublished data) suggests that selection for higher in-vitro digestibility at a given level of dry matter yield may be successful. Conversely, a variety bred for more vigorous regrowth, even if early-heading and potentially high in head number, would enable the farmer to have more frequent grazings with a high level of digestibility. Thus, higher planes of nutritive value can be arrived at by two, possibly concurrent, lines of approach.

Breeding efficiency would be enhanced if the desired ideotype (Donald, 1968) could be discovered at an early stage. With the evidence presently available it can be assumed that seed yield is closely correlated with vigour and, in tufted grasses, a tall growth habit. If this assumption is valid, early detection of useful plants becomes feasible. In old leys, of progressively declining productivity, very few such plants occur (van Wijk, unpublished data). The dominant type appears to be of poor vigour, funnel-shaped or flat-growing, and is apparently of strong competitive ability in mixture with erect types which yield well when alone (Montgomery effect; de Wit, 1960). By developing varieties consisting of uniformly vigorous, erect plants persistence in leys may automatically be improved. Tillering characteristics at an early stage may also provide information about the ultimate value of a plant (Boonman, 1971b).

It has often been said that the performance of spaced plants bears little relationship to its potential in a community. This does not seem to be relevant to spreading species such as Rhodes grass as individual plants can only be evaluated in little swards of their own (Bogdan, 1964). As for the tufted grasses, tropical pastures in Kenya rarely form closed swards but consist of a community of individually recognizable plants. Consequently, plants may confidently be evaluated at close spacings that are convenient for handling.

It is concluded that the breeding of tropical grasses for the intensive pasture areas of Kenya should have the following major objectives: even heading date, good plant vigour, potentially high head number, high seed setting, persistence and high nutritive value.

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