FIRE EFFECTS ON A UGANDAN SAVANNA GRASSLAND

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ABSTRACT

Fire protection, early and late triennial burns, early and late annual burns and two burns per year were applied to four grazing managements of a savanna pasture dominated by Cymbopogon afronardus, Hyparrhenia filipendula *and* Themeda triandra *with a shrub layer to* c.3.5 m *of dense* Acacia hockii. *After only three years marked visual differences were apparent in both the grass sward and the structure of the shrub layer.*

The unburnt treatment became a tangle of interlocked branches of A. hockii, *which restricted cattle movement. Early annual burning and two burns per year both produced a relatively open grassland with stunted bushes. Late annual burning caused a denser bush growth than early burning but as the bushes were mainly single stemmed with few low branches, cattle movement was not greatly impeded.*

Brachiaria decumbens, *the only common, desirable, grazing grass, was encouraged by fire protection but so was the highly unpalatable tussocky* C. afronardus. *When* C. afronardus *is controlled, fire protection would greatly increase the carrying capacity of these pastures; the increased bush biomass associated with fire protection is only a seral stage in true tree development, which would not then impede cattle.*

T. triandra *and* H. filipendula *increased in frequency with frequency of burning and both are relatively undesirable grazing species.*

Early burning caused stunting of the sward, lower frequencies of B. decumbens *and higher frequencies of* T. triandra *and* H. filipendula *compared to late burning. Thus, when burning is desirable to reduce the biomass of* C. afronardus, *a late burn will minimise damage to desirable sward characteristics. If such a burn is set against the wind and in weather which will minimise fire temperatures, few bushes will be burnt to the ground, to subsequently coppice, but many low branches will be pruned to aid cattle movement.*

INTRODUCTION

The vegetation of Ankole district, Uganda has been mapped and described by Langdale-Brown, Osmaston and Wilson (1964) as a major form of dry *Acacia* savanna complex induced by burning and grazing. The herb layer is dominated by *Themeda triandra* in the valleys and *Cymbopogon afronardus* on the hills. The sward is dense and grass leaves attain heights of 0.5-1.5 m. The undisturbed woody vegetation consists of an upper-storey dominated by *Acacia gerrardii* to 13 m, a second storey to 7 m (—10 m) dominated by *Acacia hockii* and an under-storey to 3 m, also dominated by *A. hockii*, which is normally burnt back every year and so fails to increase in height.

Chain-clearing of the woody vegetation was carried out on 400 sq. km in 1962 as an anti-Tsetse fly measure (Wooff 1964). Records of subsequent regrowth (R. J. Johnson, unpublished) indicated that the frequency of *A. hockii* was unaffected by this measure but coppice regrowth appeared and this was only kept in check by regular burning. Total fire prevention on cattle ranches had allowed thicket to develop and in some areas cattle were unable to gain access five years after the chain-clearing programme. The advisability of burning such vegetation was a hotly debated topic amongst local graziers and Ministry of Animal Resources field staff, but in the complete absence of data grass burning was a standard practice

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in the district and was often achieved twice per year. Fires normally spread with the wind but due to the large numbers of roads and tracks there is also a considerable amount of fire movement against the wind. The primary purpose for burning was to obtain grass regrowth during dry times.

Ankole has valuable cattle and game resources, in which the Uganda Government is investing large sums of development money (Sacker and Trail, 1968). The current cattle population is 500,000 and the environment is such that it will support annual growth rates in excess of 0.35 kg/day for ranged cattle (Trail, Sacker and Fisher 1971) and over 100 kg/ha (Harrington and Pratchett 1974). Current ranching development is being jeopardised by an apparent increase in *A. hockii* bushes and the tussock grass, *C. afronardus*. This grass is unpalatable to cattle (Harrington and Pratchett 1972) and cattle have been known to die of starvation when an abundance of it, in green condition, was available (personal observation). *A. hockii* is a serious weed of grassland in many parts of East Africa and its character and the problems of control have been detailed by Ivens (1958), Harker (1959) and Harrington (1968, 1973). One of the more important characteristics of this species is its ability to coppice even when burnt or cut back several times per year.

Ford and Clifford (1968) report how the spread of the Tsetse fly *Glossina morsitans* Westw. and associated *Trypanosomiasis* disease drove the cattle and pastoral Abahima tribe from many parts of Ankole during the period 1907-1960. Local pastoralists, able to remember back to 1920, claim that *C. afronardus* was so uncommon around this time that they would walk many kilometres to collect this plant for medicinal preparations. On their return in the 1960's after the Uganda Government's successful campaign to eliminate the Tsetse fly, they found *C. afronardus* had increased in frequency to cover an estimated 40 per cent of the ground cover. It seems probable that a change in the grazing and/or fire pattern induced by the depopulation of the area was responsible for this. Whether or not this reported increase in *C. afronardus* is accurate, the ecology of this grass remains supremely important to the economic development of the area. Harrington and Pratchett (1974*a*) have shown that the removal of *C. afronardus* from fully stocked pastures improved cattle growth rates by *c.* 30 per cent but the rate of recolonization can be extremely rapid, with all improvement eliminated within five years, under a management favourable to this species.

Fire is probably the dominant ecological influence in this area and information to quantify it is urgently required for management purposes. This paper deals with vegetation changes after only three years of fire treatment. Visual observations were continued for a further three years but circumstances in 1972 prevented any further data collection. In the circumstances it seems worthwhile to publish the available data.

METHODS

The experimental site was chosen to be representative of the dense regrowth of *A. hockii*, which is common in areas of cut over vegetation in this part of Africa. The herb layer of the experimental site was dominated by *C. afronardus* and the combination of the dense bush and large tussocks made it extremely difficult for cattle to penetrate it. It had previously been burnt in 1964.

Six fire treatments were chosen as being representative of local burning practice or which were practicable burning managements for a grazier:

1. No burning
2. Burning early in the long dry season every third year (usually early June)
3. Burning late in the long dry season every third year (usually late August)
4. Annual burning early in the long dry season
5. Annual burning late in the long dry season
6. Annual burning early in the long dry season and again in the short dry

season (usually January). The January burn failed in 1969 due to continuous rain.

These fire treatments were repeated on four grazing managements:

A. *C. afronardus* was removed (see below). The area was sub-divided into six paddocks of 0.2 ha and rotationally grazed by a *c*. 300 kg bullock. The paddocks were spelled for *c*. eight weeks prior to burning to ensure sufficient fuel for a hot burn.

B. *C. afronardus* was removed. The area was not fenced or spelled prior to burning and was continuously grazed by herded cattle at an average stocking rate of *c*. 0.4 beasts ha^{-1} (beast average weight = 300 kg).

C. Natural pasture. Grazing was as in B except that temporary fences were erected for spelling prior to burning.

D. Natural pasture. Grazing as in B with no spelling.

The fire treatments and grazing managements were arranged in a 6 $\times$ 4 split plot design, each treatment/management being carried out on 0.2 ha. Two replicates started in July, 1966 and two in July, 1967. This separation of the starting dates of half the replicates by a full year and the uncontrolled nature of the grazing of three of the four managements was controlled by available funds and labour.

In July of the year of starting the whole area was burnt off except for the scheduled unburnt treatments. *C. afronardus* was then hoed out of managements A and B. Hoeing of this species as a pasture improvement measure has been described by Harrington (1973), and is normally undertaken after burning. In both 1966 and 1967 good rains were obtained in the September-November period (> 275 mm), grass regrew after the burn and botanical analysis was carried out in November and repeated after three years of treatment. The decision to exclude the unburnt treatment from the burning pretreatment was made in order that any difference between burnt and unburnt treatments would become apparent in as short a time as possible. Thus the three-year burning effects are compared with a treatment unburnt for five to six years. Whilst not ideal in design it was considered justified due to the urgency with which a fire management policy for a developing ranching scheme was required.

Herbs

The herb layer was analysed by:

(1) measuring the percentage total crown cover by *C. afronardus*. A tape measure was placed diagonally across each plot and the number of cm covered by this species was expressed as a percentage of the length of the diagonal;

(2) placing a metal ring of 0.9 m diameter at 3.6 m intervals on the same plot diagonal to give 16 recordings per plot. The presence or absence of each grass species was recorded. *Cyperaceae*, *Leguminoseae* and other herbs were also recorded for presence and absence as separate vegetation classes. Any species or vegetation class estimated to be contributing more than 20 per cent by volume of the total herbage within the quadrat was marked as "dominant". At the beginning of each recording session sample quadrats were cut until the observer was satisfied he could make this estimate satisfactorily.

The pasture on the areas was a dense sward dominated by grass species. The early burn treatments were carried out as soon as the vegetation would carry a a total burn. Earlier burns were possible in practice, but left sizeable patches of unaffected vegetation. Practice burns outside the experimental area were used to ensure the desired burn was achieved. Early burns were carried out on grass that was in the post-flowering stage but which still showed a fair amount of fresh material, although growth had almost ceased. Late burns took place when the grass was dormant and had dried off, excepting *C. afronardus*, which showed xerophytic properties in retaining green, but dormant, tillers throughout the dry seasons. The January burn of the two-burn treatment took place on grass which was in the post-flowering stage and not actively growing, although not totally dry.

In April 1971 soil samples were collected from managements A and D on the two replicates started in 1966. The samples were taken from 0-15 cm depth, after removal of the surface litter, at nine points on a 3 × 3 grid at 9 m intervals in the centre of the plot. The three samples on each horizontal line were mixed and sub-sampled, thus three samples from each plot were analysed according to procedures described by Foster (1971).

Monthly phenological records of the main species were made but have only been referred to in general terms in this paper.

In April 1971 ten *C. afronardus* plants were chosen at random on each fire treatment on management A and the length of the most recent leaf on a non-reproductive, healthy tiller was measured.

Shrubs

Sub-plots 15 m square in the centre of each plot were measured for bush content in the year of starting and after three years of treatment. Each bush was recorded for number of stems, height of each stem and whether each stem was more or less than 12.5 mm (0.5 in) in thickness at the base. A quick method of making these measurements used a lightweight metal pole of 12.5 mm (0.5 in) thickness with a hard steel point. The pole was painted in 0.3 m (1 ft) bands of colour as a ranging pole. The height of each stem could be quickly assessed by comparing it with the pole, the thickness of the base was assessed as being thicker or thinner than the pole and the steel point was used to scratch the soil at the base of the bush to indicate that it had been recorded.

Fire temperature was measured by using THERMOCOLOR temperature sensitive paint (a Faber-Castell product). The paints were applied in 5 cm stripes to 25 × 5 cm metal strips, which were suspended from metal fence posts at heights of 30, 90 and 180 cm above the ground. The metal strips were not allowed to make direct contact with the fence post, as the heat conduction into the post affected the behaviour of the paint. Three posts were positioned randomly on each treatment/management plot. The paints used changed colour if the temperatures achieved exceeded 80, 175, 340, 560 and 715°C.

The phenology of *A. hockii* was assessed monthly by walking diagonally across each treatment/management plot. An estimate was made of the percentage of bushes present, which were producing new leaves, extending shoot length, flowering, setting seed and shedding seed. Each plot was then classified into >50%, 10-50%, <10% or nil for each of the above parameters.

TABLE 1

Rainfall (mm) over the experimental period

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1966	60	50	82	106	81	35	8	53	159	52	87	30	803
1967	60	17	66	148	90	1	9	15	37	135	115	60	753
1968	21	101	153	180	58	54	54	13	27	136	116	79	992
1969	71	154	129	95	47	8	0	28	47	142	217	42	982
1970	29	10	46	106	48	0	21	91	36	119	69	43	618

The rainfall for the experimental period is recorded in Table 1 and illustrates its bimodal nature. Mean monthly maximum and minimum temperatures were 27°C and 15°C respectively. Due to proximity to the equator temperature differences between months were small.

TABLE 2.

Percentage frequency (f) and dominance (d) of herbs on grazing management A receiving six fire treatments

Burning treatment	None f:d	Early Triennial f:d	Late Triennial f:d	Early Annual f:d	Late Annual f:d	Twice Per Year f:d	Significance f:d	L.S.D.‡
Brachiaria decumbens	83:27	98:19	95:50	94:30	92:23	78:17	NS:NS+	
Cymbopogon afronardus	67:44	69:37	61:30	47:19	53:22	45:14	NS:*†	25.6
Digitaria maitlandii	58:6	64:5	72:8	73:5	72:6	64:11	NS:NS	
Hyparrhenia filipendula	58:6	92:16	84:14	97:36	87:31	89:31	***:NS	14.5
Setaria trinervia	23:2	28:5	28:3	23:5	6:2	53:8	*:NS	29.7
Themeda triandra	19:0	39:9	45:3	39:14	37:6	50:11	NS:NS	
Legumes	30:0	53:0	61:2	80:2	67:0	83:3	*:NS	38.0
C. afronardus cover	28	17	12	5	4	4	***	11.0

+NS = no significant difference between fire treatments
†*, **, *** = a significant difference between fire treatments at the 5%, 1% and 0.1% level respectively
‡L.S.D. = least significant difference at P = 0.05

TABLE 3

Percentage frequency (f) and dominance (d) of herbs on grazing management C under six fire treatments

Burning treatment	None f:d	Early Triennial f:d	Late Triennial f:d	Early Annual f:d	Late Annual f:d	Twice Per Year f:d	Significance f:d	L.S.D.‡
Brachiaria decumbens	62:25	91:39	94:42	94:19	89:39	96:30	†**:NS+	21
Cymbopogon afronardus	50:31	72:55	70:55	73:55	80:45	72:41	NS:NS	
Digitaria maitlandii	19:0	55:5	42:2	77:6	59:2	45:5	***:NS	23
Hyparrhenia filipendula	20:2	52:0	39:2	81:6	86:11	68:20	***:**	22:12
Setaria trinervia	8:5	2:0	34:2	17:0	9:4	22:4	NS:NS	
Themeda triandra	0:0	23:0	36:5	36:0	44:8	77:16	***:**	15:10
Legumes	26:0	53:0	66:5	80:0	75:0	72:0	*:NS	39
C. afronardus cover	39	41	35	33	22	15	NS	

+NS = no significant difference between fire treatments
†*, **, *** = a significant difference between fire treatments at the 5%, 1% and 0.1% level respectively
‡L.S.D. = least significant difference at P = 0.05

TABLE 4

Frequency of Acacia hockii *bushes and stems per ha, average number of stems per plant and average height of bushes after three years of burning treatment*

Burning treatment	No burn	Early triennial	Late triennial	Early annual	Late annual	Two burns	L.S.D.†
Bush frequency per ha	2,373	3,153	3,266	3,581	4,368	3,282	476
Stems <12 mm per ha	844	5,734	5,927	5,184	8,751	4,623	1,161
Stems >12 mm per ha	2,450	2,332	1,870	1,748	1,720	1,523	292
Total stems per ha	3,294	8,066	7,797	6,932	10,471	6,146	1,236
Percentage stems <12 mm	26	71	76	75	83	75	
Stems per plant	1.39	2.55	2.40	1.93	2.40	1.87	0.22
Average bush height (m)	1.77	1.26	1.14	0.97	0.94	1.06	0.11

†L.S.D. = Least significant difference at P = 0.05

RESULTS

Changes in the vegetation over the period of the trial could not be examined statistically due to the no-burn treatment not receiving the same initial burning pretreatment as the rest of the area. The vegetation showed significant differences between treatments after three years of treatment and these are presented here.

Botanical composition of the sward after fire treatment on grazing managements A and C are given in Tables 2 and 3. There was little difference between managements A and B or C and D as far as botanical composition was concerned; the results for managements B and D are not presented here but are available on request from the author.

For simplicity only species that were influenced by fire are shown in Tables 2 and 3. Other species and vegetation classes that were commonly present were *Andropogon dummeri, Chloris gayana, Loudetia kagerensis,* sedges and dicotyledonus herbs other than legumes.

The structure of the shrub layer is summarised in Table 4. Only data for *A. hockii* is presented as other species were too infrequent to be analysed. There was no evidence that any treatment encouraged the establishment of any species of shrub or tree that was not previously present.

Figure 1 records when more than 50 per cent of the bushes were demonstrating the indicated activity, i.e. flowering, seeding, shoot extension. Flowers were produced in axillary racemes near the end of the shoot at the cessation of shoot extension. Shoot extension took place during the long rains, the main flowering occurred in the short January-February dry period and seed was shed in April at the height of the short rains and immediately prior to the May-August dry period.

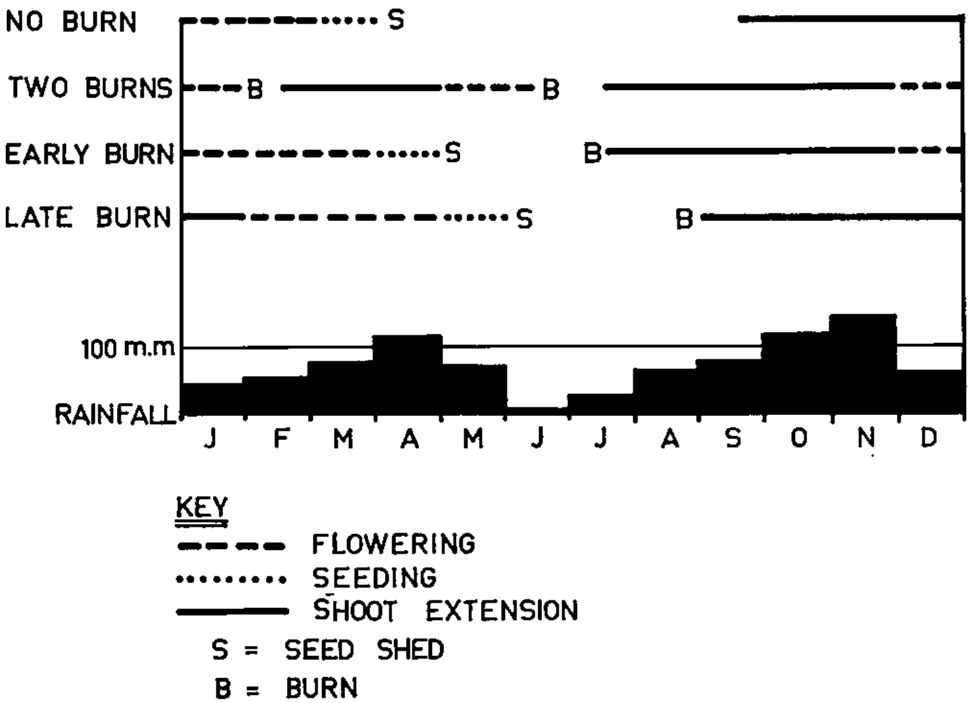

FIGURE 1

The phenology of *Acacia hockii* under different burning regimes.

At the beginning of this dry period a second flush of leaf appeared, with no accompanying extension growth, and a certain amount of flowering took place. These flowers rarely resulted in seed set.

Burning, at any season of the year, was always followed by shoot extension growth on those parts of the plant affected by fire, but the tops of the taller bushes behaved similarly to the bushes in the unburnt treatment. Thus, burning early in the long dry season stimulated shooting and flowering earlier than on the unburnt treatment whilst late burning did not greatly influence the time of shooting. Burning twice per year prevented seed set on the bushes burnt in January, but as the fire temperatures were low, many of the taller bushes escaped and produced viable seed. These results are in agreement with those of Hopkins (1963).

Table 5 details the chemical analyses of the soils after three and a half years of fire treatment. The low pH, OM %, P, Ca and K values for the early triennial burn treatment were anomalous and tests of the other two replicates did not confirm them.

The results of fire temperature measurements were variable due to variation in wind speed and direction but as a general rule late burns were hotter than early burns and the biannual burn was cooler than the annual burn.

TABLE 5

Soil analysis after three and a half years of burning treatment

Burning treatment	pH	OM %	P ppm	Ca mg/100 g	K mg/100 g	N ppm
No burn	5.00	2.68	6.1	30.5	21.5	75.3
Early triennial	5.04	2.39	3.5	29.2	17.6	65.7
Late triennial	5.34	2.83	9.5	39.8	31.7	68.2
Early annual	5.33	2.74	7.3	39.6	23.4	62.0
Late annual	5.30	2.87	10.6	44.6	27.7	63.4
Two burns	5.45	2.49	10.2	40.9	23.1	56.1
L.S.D. ($P = 0.05$)	0.26	0.25	5.65	8.4	9.0	6.8
Low/high values*	5.2/6.2	3.0/6.0	5/20	35/200	15/50	

Nitrogen (N) determination indicates the easily mineralizable nitrogen soluble in boiling water (Keeney and Bremner 1966). The other analyses have been described by Foster (1971).

*Below the low value a soil amendment is likely to benefit most crops. Above the high value a soil amendment is unlikely to benefit most crops (H. Foster, mimeo).

DISCUSSION

Visual description

A description of the visible characteristics caused by the fire treatments is worthwhile in lieu of photographs, which are available for inspection. These characteristics were apparent after three years of treatment and had intensified by 1972 when the last inspection was made. The data will be used to support these observations.

The unburnt treatment had taller bush than other treatments and the intertwined branches reached almost to ground level. The herb layer was dominated by tall *C. afronardus* tussocks and *C. afronardus* litter but where gaps remained between the tussocks *B. decumbens* was vigorous and dominant.

Triennially burnt treatments appeared similar to the unburnt treatment in the year of burning but after burning they had shorter grass and more open bush.

Annual later burning severely pruned the lower branches of the bushes, allowing cattle much more freedom of movement than in the unburnt treatment. Some bushes were burnt to the ground and coppiced. The *C. afronardus* tussocks were smaller than in the unburnt treatment, which also aided cattle movements.

Annual early burnt and biannually burnt treatments both appeared similar and startlingly different from the late burnt treatment. A few larger trees prevailed but the majority of the shrubs were reduced to within the herb layer and the appearance was an open, treed grassland. Unfortunately the grass was also stunted and appeared to comprise mainly of flowering culms of the fire climax *T. triandra* and *H. filipendula*. *B. decumbens* was noticeably scarce. The grass bases were pedestaled indicating soil erosion between the plants; there was no evidence of erosion on the other treatments.

A feature of all burnt treatments was the flowering of grasses, which took place in the season following the burn. Flowering was sparse in the absence of burning. The height of the flowering culms was in inverse proportion to the frequency of burning.

Cymbopogon afronardus

Managements A and B were initially cleared of this species. There was no significant difference between fire treatments in the frequency with which *C. afronardus* appeared on this management three years after clearing, so it appears that fire did not influence the recolonization process. The size of the individual plants was strongly affected by fire, however, and the crown cover by *C. afronardus* was 28 per cent on the unburnt treatment and less than 10 per cent on the three annually burnt treatments (Table 2).

On the natural pasture (managements C and D) the percentage crown cover by *C. afronardus* was also higher on the unburnt treatment but not significantly so (Table 3). Mean leaf lengths were 49 cm on the biannually burnt treatment, 65 cm on annually burnt treatments and 80 cm on unburnt plots. Theron (1937) also remarked on the stunting effect on the herb layer of annual burning but on much drier country than the current trial.

The failure of fire to affect recolonization rates suggests that a change in the burning regime during the absence of graziers driven out by the Tsetse fly was not responsible for the previously mentioned district-wide increase of *C. afronardus*. These trials were carried out on small plots surrounded by dense *C. afronardus* and it is possible the high seed challenge smothered fire effects, however.

Reduction in the frequency of burning was not the only result of the evacuation of the cattle from Ankole. A reduction in grazing intensity was also experienced. It is difficult to assess what effect this might have had because the wild herbivores remained and there is some disagreement on the population numbers of these. Wooff (1968) records that the elimination of game from northern Nyabushozi (3,000 km^2) produced only 10 animals (excluding zebra, *Equas burchelli*) per km^2 and most of these were small herbivores, e.g. bushbuck, bush duiker. Such a population would indicate a biomass of approximately 20 kg/ha at least half of which would be comprised of browsing rather than grazing animals. This is a far lower estimate than people familiar with the area would have made (personal communications) and a fraction of that in the adjacent Queen Elizabeth National Park, where Field and Laws (1970) have measured 295 kg/ha. Between 1942 and 1960 the cattle population of Nyabushozi County fell from 60,000 to 8,000 and the estimated cattle biomass from 60 to 8 kg/ha. Even if Wooff's (1968) estimate of the game population was a gross underestimate, it is probable that a reduction in the grazing biomass of this order would cause changes in the herb population. Ford and Clifford (1968) mention a great increase in bush and trees during the period of reduced cattle population and ascribe this to removal of a small elephant population, the cessation of cutting bush for kraal building and a change in the grass burning regime, which, they suggest, might increase *Acacia* seed germination rates. It is probable from the current studies that this increase in bush would be primarily due to reduced frequency or change in pattern of burning, but is, in any case, evidence for the instability of the vegetation during this period. The two counties Kajara and Kashari, both of which were heavily grazed, with an estimated biomass of 180 and 80 kg/ha respectively during the depopulated period in Nyabushozi, are free of *C. afronardus* except for small isolated patches. Harrington and Pratchett (1974*b*) have shown that a grazing pressure of 300 kg/ha prevented recolonization of *C. afronardus* except in protected sites, e.g. under thorny bushes but that 100 kg/ha allowed re-establishment throughout the pasture; this again was under conditions of heavy seed challenge.

The evidence can be summarised by saying that it is probable that the combination of reduced grazing pressure and reduced burning encouraged the spread of *C. afronardus* to the detriment of the carrying capacity of the land.

Brachiaria decumbens

This is the species of highest potential economic value to Ankole (Harrington and Pratchett 1972). It has a stoloniferous habit, which makes it an important colonizer of bare ground between the tufts of the fire climax grasses, it is relatively favoured by heavy grazing (Harrington and Thornton 1969) and it has a relatively high crude protein and low crude fibre content (Long *et al.*, 1969). Over much of Ankole, when *C. afronardus* is removed and the remaining sward is subjected to fairly heavy grazing, this species becomes dominant (Harrington and Pratchett 1974*b*). It is of utmost importance that the reaction of this species to fire is understood, because it is probable that this will become the most important grass for beef production in Ankole.

At first glance it would appear from Tables 2 and 3 that fire encourages *B. decumbens* because the frequency of this species is less on the unburnt than on the burnt treatments. This is an illusion, however, for visual comparison of an unburnt treatment with an annually burnt treatment at a point where they have a common boundary, shows a severe reduction in the yield of *B. decumbens* on the burnt plot. The lower frequency of *B. decumbens* on the unburnt treatment is due to increased competition by *C. afronardus*.

Hyparrhenia filipendula *and* Themeda triandra

These two species are dealt with together, because they have a similar tufted habit and a similar nutritive value (Long *et al.*, 1969). *T. triandra* is dominant on valley bottom pastures in Ankole but tends to give way to *H. filipendula* on the hillsides. Although *T. triandra* was not a very common grass on the pastures in the present work, it is amongst the five commonest grasses in Ankole and its reaction to fire is, therefore, very important.

T. triandra was severely depressed both in frequency and dominance on the unburnt plots and was most common on the two-burn plots on all four grazing managements. Even burning every third year significantly increased this species in some cases. This partially disagrees with conclusions reached by West (1965) in his review of fire effects on African pastures, in which he suggested that *T. triandra* was negatively affected by the accumulation of litter rather than positively encouraged by fire. Whilst there is reason to suppose that the reduced incidence of *T. triandra* on the unburnt and trienially burnt treatments was due to litter accumulation the increase in *T. triandra* on the two-burn compared to annual burn treatments may be a positive response to fire. West (1965) also concluded that soil moisture depletion due to regular burning discouraged *T. triandra* but in the current work the dwarfing of the grass in the early annual burn and two burn treatments, probably due to lack of soil moisture rather than chemical depletion (see Table 5), was accompanied by an increase in *T. triandra*.

H. filipendula was distinctly depressed on unburnt plots under all managements. It was also depressed under triennially burnt treatments when compared with annually burnt treatments on managements C and D, suggesting that an important factor might be competition from *C. afronardus*. There was no evidence that the two-burn treatment was more favourable to this species than was the annual burn.

Both *T. triandra* and *H. filipendula* can be said to be highly favoured by regular burning, both are amongst the five most common grasses in Ankole and as neither is considered by Long *et al.* (1969) or Harrington and Pratchett (1972) to be desirable grazing grasses, the economic implications of their encouragement by current burning practices in Ankole are great.

Other grasses

Of the 24 other grasses found growing within the area only *Setaria trinervia* showed a significant response to fire. This was probably due to the greater effect of competition from the commoner grasses than an intrinsic insensitivity to fire.

Herbs

There was no evidence that fire affected the sedge or herb content of the pasture, with the exception of legumes. Legumes were strongly depressed on the unburnt plots, less depressed on the triennially burnt plots and most abundant on the annually burnt and two-burn plots. A possible explanation for this is revealed in Table 5, where the results of soil analyses are detailed. H. L. Foster (personal communication) states that in these soils aluminium ionizes below pH 5.2 and would then have a toxic effect on legumes. The effect of annual burning was to lift the soil pH from *c.* 5.0 to *c.* 5.3. It seems more probable, however, that legumes are depressed by the build-up of litter or by heavy shading from tall growing grasses. It has been observed that many legumes grow and flower actively after a burn when there is little competition from grass (Harrington and Ross 1974).

Acacia hockii

The data in Table 4 explain most of the assertions based on the visual appearance of the treatments. It is interesting to note, however, that the unburnt treatment had the densest bush in appearance but the lowest number of bushes per ha. and the lowest number of stems per bush. Clearly the density of the bush was caused by the intertwining, low branches on the unburnt treatment.

The higher bush frequency on the annually late burnt treatments accounts for the denser appearance of this treatment compared to the early burnt treatment, but the data fail to demonstrate the stunted appearance of most of the bushes on the latter treatment. West (1965), in a review article, recorded no instance of a late burn being less efficient than an early burn in reducing woody growth in Africa. The results in this trial appear to be unique.

There are three possible explanations for the increase in the frequency of bushes and stems after burning. The spreading canopy and vigorous growth of unburnt bushes might suppress the smaller bushes by competing for light and/or moisture and nutrients, whilst the more open canopy of the burnt plots would allow smaller plants to develop. The physical damage inflicted by the fire certainly caused an increase in the number of stems per bush and might also have caused shooting from root buds. The fire might cause seedling establishment, as suggested by Harker (1959) but the increase in bush frequency was not immediately due to seedling establishment for very few seedlings were recorded. Although fire might cause sprouting from root buds, excavations revealed no underground connection between bushes. Thus it seems that small bushes were lying dormant beneath the canopy of the mature specimens and were not recorded until a fire reduced competition from the larger bushes and allowed them to develop. This would explain why the increase in the number of bushes on the triennial burnt plots did not appear to be made up of seedlings. Seedlings, however, must have gained establishment at some time or another, but may have lain dormant for some years.

Harrington (1973) recorded a similar increased bush frequency after chain-clearing of a mixed *Combretum*/*Acacia hockii* woodland when the frequency of *A. hockii* increased from 90 to 1,500 per ha presumably also due to removal of competition between mature and young plants.

The height pattern of the bushes on the different burning treatments indicates one way in which the bushes are affected by fire. All treatments, but not all replicates, had at least one bush, which had achieved a height in excess of 3.6 m and could be considered immune to fire. It is interesting to note that the two-burn treatment had the greatest number in this height class; this may have been due to the low temperatures of the burns failing to reach the crowns of the trees but pruning side branches and stimulating apical growth. The importance of this is apparent when the considerable increase in the average height of the unburnt bushes is taken into account. Clearly these bushes are rapidly achieving tree height and burns, which would prune off lower branches without affecting the apex, would allow the formation of the classical African savanna tree with its clean stem and umbrella crown. Such trees offer minimum impedance to the grazing animal but offer light shade to both animals and herbage. Only infrequent burns would be necessary to achieve this vegetation type under a heavy grazing regime.

Soil

Annual burning increased the available calcium and phosphorus when compared with the unburnt plots. Daubenmire (1968), reviewing American work, concluded that grassland burning contributed very little ash to the soil. Moore (1960) in Nigeria found that early burns increased exchangeable calcium and available phosphorus although late burns did not, but other workers such as Cook (1939) did not obtain similar results. In the current work there was no difference between early and late burns. In the opinion of H. Foster (personal communication) the increase from 6 to 10 ppm phosphorus and the increase in calcium from 30 to 40 ppm between the unburnt and annually burnt treatment might have a significant effect on grass growth, as in both cases, burning caused an increase above the critically low value (see Table 5).

The increase in pH by >0.3 due to burning has been observed by other workers (Daubenmire 1968; Moore 1960). Although this rise might affect legume growth in these soils it is unlikely to affect grass production directly (H. Foster, personal communication).

Organic matter in the soil did not seem to be affected by the fire treatments. This agrees with most other results in this field. Where an effect by fire on soil organic matter content has been observed, it has been ascribed to changes in the herb and flora vigour of growth rather than a direct fire effect (West 1965).

Soil nitrogen content was reduced slightly but significantly with increasing frequency of burning. There was no difference between early and late burning. It would appear that the increased legume frequency was unable to offset nitrogen losses due to burning. Cook (1939) found similar small nitrogen losses due to burning but Moore (1960) found that burning increased soil nitrogen particularly on the early-burned treatment. In Moore's experiment early-burning had an invigorating effect on the herbage and it was probably the vigorous herb growth that was responsible for the increased soil nitrogen. Although in the current experiment the treatment with the least herbage bulk (visual assessment), the two-burn treatment, had the lowest soil nitrogen, annual early-burning did not lower soil nitrogen more than annual late-burning, yet the early-burnt plots had a similar unthrifty appearance to the two-burnt plots.

It seems probable, therefore, that the lower plant vigour on the early-burn and two-burn treatments are due to a deterioration in the soil-moisture relations, rather than to lower nitrogen or other nutrient availability. West (1965) attributed most deleterious effects of fire to such a cause. Plans for direct measurement of soil moisture were unfortunately frustrated.

CONCLUSIONS

As an annual practice grass burning causes a reduction in the DM production and nutritive value of the Ankole grassland (Table 6) and it causes an increase in the frequency of shrubs. Burning at the beginning of the dry season exposes the soil surface for several months, increases water erosion and probably depresses water penetration of the soil (Rowe 1948).

TABLE 6

Dry matter (kg ha^{-1} yr^{-1}), crude protein (%) and crude fibre (%) yield on a burning and cutting trial in Ankole (after Thornton 1966)

Cutting interval	4 weeks		8 weeks		12 weeks		24 weeks		52 weeks	
Burnt (B) or Unburnt (U)	B	U	B	U	B	U	B	U	B	U
DM	1,010	1,260	2,000	2,680	1,810	2,800	2,680	5,110	4,080	4,050
CP	8.2	8.0	8.0	7.0	5.9	5.9	4.8	3.8	3.7	3.1
CF	32.4	32.2	33.2	32.2	35.0	32.5	36.1	34.6	35.5	33.1

Strategic cool burns, at the beginning of the rains and against the wind and at intervals of several years may help to stimulate tree rather than thicket development, by pruning off lower branches and stimulating apical growth. Grass below savanna trees remains green longer into the dry season and is normally composed of species desirable for grazing.

Should the trees subsequently be regarded as an agricultural nuisance they can be poisoned with picloram (Harrington 1973), and are more easily dealt with than shrubs because they are fewer in number and have exposed trunks.

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