wind; (2) heaps respond similarly with respect to wind conditions, i.e. under moderate wind, the temperature soars to more intense heat than when high wind prevails; and (3) burning efficiency is enhanced by piling combustible matter into heaps.

RECOMMENDATIONS

Recommendations based on the above, to provide for more appropriate and efficient routine burning procedures may be put forward: (1) Light to moderate wind (5 mph), is of greater advantage than brisk wind (12 mph); the former inflicts more destructive action through higher temperatures. Thus, about midday appears to be the appropriate timing for burning. (2) Naturally congested waterhyacinth forming carpets of combustible matter should be piled into heaps prior to the application of routine burning.

CONCLUSIONS

Considering the various aspects of the environmental complex, it seems desirable to recommend shortening of the period (March to July) of routine burning practices. The suggestion is to confine the campaign for routine burning to the months of March and April. Experience has shown that by March both natural accumulations and heaps attain sufficient drying, thus readily combustible matter is, by then, guaranteed. The advantage of burning in March is that it safeguards against prolonging the opportunity for dispersal. On the one hand, early burning would undoubtedly destroy vegetatively dormant forms which might otherwise remain to rejuvenate when moisture requirements are met on the commencement of early rains. On the other hand, burning later than the end of April has its drawbacks. The climatic conditions become favorable with a progressive increase in relative humidity. Dry, spongy-textured waterhyacinth, being readily able to absorb atmospheric moisture, would resist burning or at least render operations less efficient.

The findings of the present studies suggest possible amendments to routine burning practices under Sudan conditions. Practical implications would certainly lead to an improvement of the traditional methods. The accomplishment of higher temperature in routine burning builds up better efficiency in suppressing seed and vegetative regeneration at innumerable potential centers of reinfestation.

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Burning As A Supporting Management In The Control Of Waterhyacinth In The Sudan

II - Backburning

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INTRODUCTION

Waterhyacinth (*Eichornia crassipes* (Mart.) Solms.) has acquired great scientific interest in the Sudan since 1958, when it was first declared a notorious weed infesting the White Nile. Its unchallenged invasion as a result of exceedingly rapid multiplication is posing a national problem of immense magnitude. Infestation habitats have provided numerous opportunities for interesting field studies in an entirely new river ecosystem. Despite large scale control efforts involving enormous expense, waterhyacinth presents several problems. A heavy infestation of these plants obstructs navigation, impedes the normal flow of water causing stagnation, hinders fishing practices, and chokes irrigation canals along the greater part of the 600-km stretch of the White Nile. Progress in pursuit of eradicating the weed is yet to be advanced and is presently a much debated topic. Both chemical and mechanical control measures have been adopted. Although the former, spraying with (2,4-dichlorophenoxy) acetic acid (2,4-D) proved fairly satisfactory, by giving rapid temporary relief, certain limitations render the more time-consuming and uneconomical alternative (mechanical removal management) inevitable under various circumstances. Chemical spraying is restricted during the cotton (*Gossypium barbadense* and *G. hirsutum* L.) growing season, July to March. The Fisheries Research Division is exercising strict control over the use of 2,4-D in breeding grounds between January and May. Furthermore, Provincial legislation prohibits the use of 2,4-D in the vicinity of villages as a precaution against harmful pollution of domestic water supplies. Unrestricted mechanical removal campaigns, on the other hand, are conducted throughout the year and wherever heavy infestation creates a serious problem. Mechanical appliances such as forks, rakes, and sawboats are used for the purpose. Masses of mechanically removed waterhyacinth are normally piled into large heaps along the dry river banks. Heaps as well as naturally stranded accumulations have become part of the riverine landscape during low-flood. Natural accumulations develop as a result of a sharp drop in water level, in low-flood, cutting off extensive marginal communities of waterhyacinth from the main course. The effects of water recession are most evident around bends, in shallow side streams, and depressions. These habitats, covered with stranded waterhyacinth populations, reveal varying degrees of congestion of masses that invariably form large carpets along the predominantly meandering banks of the river. During the dry season (January to June) under the desiccating heat of open sun, both forms of accumulation (i.e. heaps and carpets) are destined to dry into readily combustible matter. Traditional burning (routine headburning) has been the usual Land Campaign activity during the low infestation period, January to June. Moderate to vigorous prevailing winds were generally utilized to fan flames across heap and carpet accumulations. The dry, fluffy combustible debris is burned in order to guard against possible reinfestation by seeds borne in ripe capsules of dry plants. Field evidence obtained during the course of this study, has shown that unburned remnants contain viable seeds in large quantities. A small proportion of the seed crop was noted to germinate early during the rainy season, July to August. High-flood (August to October) is perhaps more suitable for germination of the remaining greater bulk of the seed-crop. Late season germination is particularly dangerous since seedlings meet better chances of establishment when the high-flood commences. In addition, sedentary young waterhyacinth plants are generally washed down into the rising river where they flourish, reproduce vegetatively, and intensify the infestation problem. Thus, the primary aim of burning has been to destroy seeds before favorable conditions commence which permit germination and successful establishment of new plants.

BURNING MANAGEMENT

Fire has long been used to destroy terrestrial vegetation in order to reach certain constructive objectives such as to initiate vigorous vegetative regeneration or to clear ground for re-establishment of dense cover through seed regeneration. Both aims serve to enhance land productivity for grazing purposes. Undesirable weeds, namely indigenous grasses in the Savanna Belt, are often destroyed by systematic burning to clear ground for seasonal (rain) cultivation. Fire has also been employed as a precaution against accidental fires which often inflict disastrous consequences on forest vegetation. Much work has been reported on such burning management. However, literature affords very limited information on burning undesirable aquatic weeds such as waterhyacinth.

The importance of burning mechanically removed and naturally accumulated waterhyacinth in the Sudan has been emphasized by Mohamed and Bebawi (10). The environmental complex in regions of accumulation, along the banks of the infested White Nile, permits large-scale burning management during the dry season, January to June. Regular burning management, which has been carried out annually since 1960, consists of headburning, invariably under brisk wind conditions. Only recently has attention been given to the characteristics of waterhyacinth fires (10).

RECOMMENDED IMPROVEMENT OF BURNING MANAGEMENT

The initial and preliminary experiments on burning waterhyacinth in the Sudan drew attention to a possible amendment of traditional burning (headburning) management. The following paragraphs aim to suggest a presumably more severe burning technique. The purpose of the investigation is to show how backburning would enhance the efficiency of the destruction inflicted upon the potentially dangerous seed crop of waterhyacinth. In the case of waterhyacinth where the danger of re-infestation depends on seed regeneration, the primary aim of burning should be the destruction of as much as possible of the bulk of viable seed lodged among and dispersed underneath heaps and carpet accumulations. Position of the seeds at the time of burning is critical. Heat generated by the traditional headburning procedure is, undoubtedly, sufficient to kill seeds engulfed in the litter of the upper strata in any form of accumulation. However, since such heat does not normally penetrate to the ground surface, then underlying seeds may not be destroyed. Undamaged seeds would remain to germinate when conditions become favorable. The danger of re-infestation through germination of undisturbed seeds (those present in accumulations where burning has not been practiced) is likely to become substantially increased by improper burning. Grant *et al.* (3) state that seeds harvested from recently burned grassland in Britain were found to have a higher percentage germination than those in nearby undisturbed grassland. Should this also be the case with waterhyacinth, then inefficient head burning of thinly littered carpet accumulations and of heaps under brisk wind conditions should be avoided.

A criterion for efficient burning is one where a high intensity of heat persists and penetrates to the ground surface. Backburning is presumably a justifiable procedure to recommend. The effects of backburning vegetation have been reviewed in the literature (2, 5, 6, 9, 13). McKell *et al.* (8) report that headfires generally inflict less damage than backfires because the maximum temperature along the vertical fire profile is well elevated above ground; backfires are more damaging, other factors being equal, because the maxima are nearer the ground and a higher temperature is attained than in headfires.

Quantity of fuel per unit area is a significant factor that influences the intensity of heat generated by fire. According to McArthur (7), with each doubling of fuel quantity per unit area, the rate of fire spread, flame height, and fire intensity are doubled. This appears to be in agreement with observations noted in Mohammed and Bebawi (10). The amount of heat emitted by burning flat accumulations of waterhyacinth is only a small proportion of the heat produced by heap accumulations. Variations in the temperatures recorded probably reflected no more than the complexity of interacting variables such as wind velocity, relative humidity, and the degree of compactness of combustible matter.

EXPERIMENTS

MATERIALS AND METHODS

All experiments at Bulli (13° 10′N., 32° 4′E.) were conducted during March to April, 1972. The experimental site represents a central region of accumulations that provide a variety of carpets and heaps of dry waterhyacinth (Figure 1).

For carpet accumulations, plot boundaries of 5 m by 5 m were marked out with pegs in the center of a moderately congested stretch where cover averages 40 cm in thickness. Round the perimeter of each plot a margin 1 m wide was cleared of waterhyacinth to guard against unnecessary spread of flame beyond the assigned boundaries. Large piles were chosen and trimmed to measure approximately 5 m^3 for heaps. Six replicates were laid out for each type of accumulation (carpet and heap) to apply backburning. Similar replication was made for headburning (traditional) treatments. The latter is intended to serve for comparisons. Prior to burning, components in accumulations were subjected to close morphological examination. A large number of random samples revealed a frail and crisp framework of individual plants representing almost the full range of the former vegetative development, from the pioneer to the late mature phases. Ripe persistent capsules, mostly dehisced, were particularly noted and were most abundant in mature components.

Climatic particulars during the time of the experiments were: air temperature 32.5 C., atmospheric humidity 29% wind from the north at 6 mph.

A portable electrothermal pyrometer, fitted with a long lead ending in a chromel alumel Thermocouple was used to record temperature at a distance of approximately 5 cm above ground surface. In each plot, the sensitive terminal was moved horizontally, to record the fire temperature at three positions: (1) where the fire was started, (2) midway in its passage, and (3) at the end. The duration of the most frequent temperature at each position was noted.

RESULTS AND DISCUSSION

Statistical analysis for the burning trials was determined by the "t" test at the 5% level.

In carpet plots receiving backburning, the components smouldered under slow advancing flame and were ultimately consumed by fire, leaving a "clean" burn. Very thin, fine residue was left on blackened soil surface. In the case of heaps experiencing backburning, the very sluggish advance of flame provided an opportunity to observe a remarkable sequence of reactions following ignition. High flame, charring of components, sparks, abundant lingering smoke and glowing of stems and roots followed in a regular sequence. At the end, it was evident that the excessively hot slow fire had sufficiently burned the components into a pile of fine, black-grey ashes (Figure 2). The ground

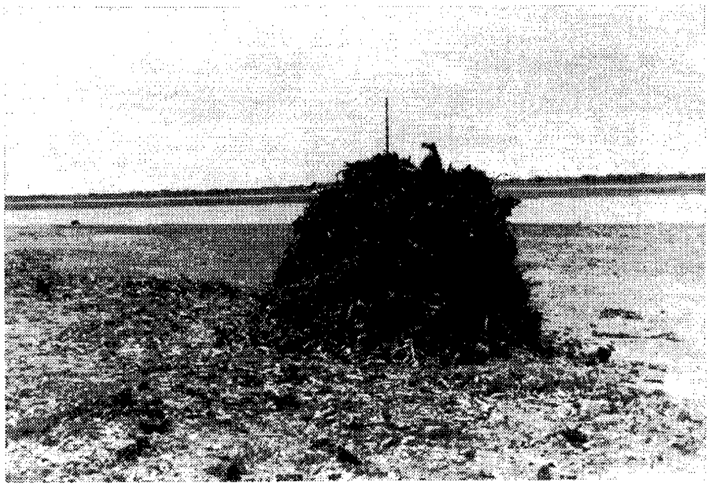

Figure 1. An accumulation of mechanically harvested waterhyacinth at Gulli, March 1972.

Figure 2. A heap of dry waterhyacinth receiving backburning at Gulli.

TABLE 1. TEMPERATURE AND DURATION OF MEASUREMENT DURING EXPERIMENTAL BURNING OF WATERHYACINTH

Waterhyacinth accumulation	Temperature (C)[a]						Duration (min)					
	Backburning			Headburning			Backburning			Headburning		
	Mean	Low	High	Mean	Low	High	Mean	Low	High	Mean	Low	High
Carpet	590	557	621	290	255	320	1.6	1.3	1.8	0.6	0.4	0.9
Heap	800	774	833	472	442	506	5.5	4.9	6.1	1.8	1.6	2.0

[a] Each mean value was determined from six replications.

surface beneath ashes revealed a distinctly burnt, black, and hard crust.

Headburning of carpet plots produced a fairly rapid spread of flame across the upper layers of the components, i.e. blades and petioles. Underlying portions, bases of petioles, stout stems, and roots were, as a rule, only superficially scorched. Heaps undergoing headburning showed a different picture of burning behavior. Flames, briskly carried by the wind, charred the components giving off vigorous smoke and abundant sparks. Subsequent smouldering behind the flame was often fanned by fresh wind, thus igniting some centers in the partially burnt components nearer ground surface. Very slow erratic burning at very low temperatures usually continued, leaving in the end a smaller heap of ashed, charred, and unburnt coarse material.

The maximum temperatures experienced in backburning of heaper waterhyacinth was over 800 C, which is approximately the same temperature reported by Whittaker and Gimingham (13), Kayll (5), and Mohamed (9) for fierce heathfires in N. E. Scotland. The moderate burning intensity resulting from backburning of natural carpet accumulations of waterhyacinth is comparable with that reported by Cook (1), Pitot and Masson (11), and Vareschi (12) from controlled burning of grassland savanna in Africa.

CONCLUSIONS

Results of experiments carried out in the present study may be summarized as follows:

1. Maximum destruction is accomplished in the excessively hot and more lasting fire associated with backburning heaped, dry components of waterhyacinth.
2. Natural (carpet) accumulations respond favorably to backburning. A fairly complete destruction is obtained, though under moderate temperatures and shorter duration than in heaps.
3. Heaps undergoing headburning leave incompletely burnt centers and a fair amount of coarse remnants on the ground surface.
4. Under headfires, carpet accumulations are subjected to light burning which is insufficient to destroy waterhyacinth litter; hence the seed crop, small as it may be, is least damaged.

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