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The possibilities of breeding long fibre agaves with a high rate of leaf unfurling and a high rate of increase in leaf length

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Summary

The vegetative development of the sisal plant is described with particular reference to two growth characteristics: rate of leaf unfurling and rate of increase in leaf length. The significance of these characteristics, particularly that of the latter, for fibre production is discussed. It is shown that a high rate of increase in leaf length is a desirable characteristic of a long fibre agave. Observations made on a number of *Agave* hybrids indicate that there is a marked negative correlation between rate of leaf unfurling and rate of increase in leaf length. The consequences are discussed and it is concluded that it will be very difficult to find the high-yielding, ideal long fibre agave, which amongst other characteristics should combine a high rate of leaf unfurling with a high rate of increase in leaf length.

Introduction

In 1929 a breeding programme for the improvement of the long fibre agaves was initiated in Tanganyika with the principal aim of selecting a more productive type than sisal (*Agave sisalana*) (Doughty, 1937). Sisal has a low rate of leaf unfurling as well as a low leaf number potential, and the same applies to the other important long fibre agaves *A. fourcroydes*, henequen, and *A. cantala*, cantala (Lock, 1957). As fibre yields are closely correlated with leaf yields a plant was to be bred which would have a high potential leaf number and a high rate of leaf unfurling. In virtually all other respects it had to resemble the agave it was to replace, i.e. sisal (Doughty, 1937). The most promising plant selected so far is hybrid no. 11648. This hybrid has a high rate of leaf unfurling and a very high leaf number potential, but it is not the ideal long fibre agave. It produces a relatively large number of short leaves during the first years from planting, it is more susceptible to diseases than sisal, and its high leaf number potential is not realized at higher altitudes because of early flowering (Wienk, 1968).

In the case of wild forms of *Agave* the general rule is that prolific leaf production is associated with small leaves (Doughty, 1937), and the question arises whether this general rule also applies to the hybrids. In other words, the problem of many short leaves of hybrid no. 11648 may be linked with its high rate of leaf unfurling.

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In the first part a description is given of some features of the sisal plant with special reference to leaf unfurling and increase in leaf length, followed by a discussion of the practical implications of these growth characteristics. In the second part some related *Agave* spp. and a number of hybrids are examined for the same growth characteristics to answer the question whether we are likely to find a hybrid with a high rate of leaf unfurling but without the disadvantage of many short leaves during the first years after planting.

Sisal

The sisal plant has been studied in fairly great detail by Wilson (1951) and his findings have been drawn upon freely in the following two sub-sections.

The uncut plant

In the vegetative phase the sisal plant comprises a short stem upon which the leaves and the central bud or spike are borne. The spike consists of the tightly furled, partly developed leaves ranging from the smallest primordium to an almost fully grown leaf. As the plant becomes older the number of spike or primordial leaves gradually increases and may reach sixty or more in a plant developed to its maximum vegetative state. Provided growth is not adversely affected each spike leaf is an approximately constant amount longer than its successor so that an older plant has a longer spike.

When a leaf unfurls only the butt end is as yet unformed and elongation does not stop until it reaches leaf sequence number 10, i.e. the tenth unfurled leaf as counted from the spike in order of unfurling. Leaves below this point, i.e. formed earlier, do not further increase in length. However, the changes in leaf length from position 1 to position 10 are relatively small so that measurements on the last completely unfurled leaf give a fairly good indication of the length of this leaf when it has reached a lower position and has become ready for cutting.

Leaves are unfurled very regularly, the average rate being dependent mainly upon soil moisture and the fertility status of the soil. Severe drought may stop the leaf unfurling completely but under normal conditions of both soil moisture and soil fertility three to four leaves are unfurled per month. Lower rates are very common on poor soils whereas average rates above four are exceptional and only occur under very favourable conditions. The systematic increase in height of the spike and thus of the last furled leaf is reflected in the regular increase in length of the unfurled leaves. Provided growth is not hampered by external factors each newly unfurled leaf is somewhat longer than the previous one and this trend continues throughout the vegetative phase. The rate of increase in leaf length, i.e. the average increase in leaf length in cm per leaf, is not completely constant but declines as the plant becomes older. During the first years after planting, however, the regression of leaf length on leaf sequence number is practically linear (Fig. 1 graphs A and B — sisal — up to first cut).

For the first few years after planting the rate of increase in leaf length usually lies between 0.7 and 0.8 cm per leaf. The rates are lower on poor soils and higher rates are unusual.

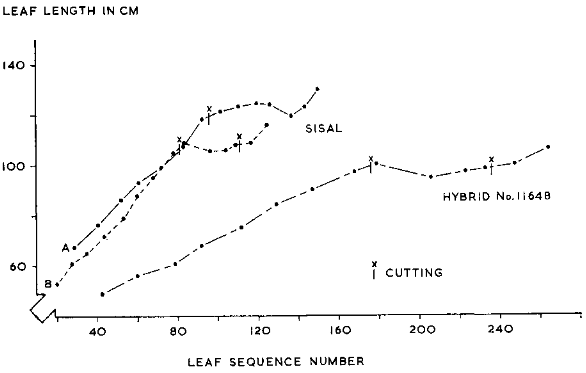

Fig. 1 Effect of cutting on the relation between leaf length and leaf sequence number for sisal and hybrid no. 11648. Curve B for sisal is from the same trial as the curve for hybrid no. 11648.

The cut plant

As the object of growing sisal is the harvesting of its leaves for fibre production, the question arises as to how the growth pattern of the plant as described above is affected by the regular removal of part of its foliage.

Cutting usually has a marked effect on the increase in leaf length in that it causes a stunting of the plant. This can be best demonstrated by plotting the length of the unfurled leaves of a cut plant against their sequence numbers. A few such regression lines are presented in Fig. 1. From these graphs it can be seen that the stunting is temporary after which the original trend is more or less restored. However, as following cuts exert a similar effect the overall result is that once cutting has started leaf length increases more slowly than for the uncut plant.

The effects of cutting on leaf production are less pronounced and, at the most, amount to a small decrease in the rate of unfurling (Fig. 2). Often no effect is noticeable and the plant continues to unfurl its leaves at a constant rate.

Practical implications

The practical implications of these growth characteristics are best discussed on the basis of a model. In Fig. 3 the theoretical regression curve (ABC) is given for an uncut plant with an initial rate of increase in leaf length of 0.75 cm per leaf. Point A indicates the tenth leaf unfurled since planting which measured 40 cm when it was completely unfurled. The subsequent leaves are each 0.75 cm longer and this trend continues until the plant is cut. Let B indicate the length of the last unfurled leaf at the moment of the first cut. The stunting upon cutting is then shown as the horizontal part BD, thus indicating that the average length of the newly unfurled leaves remains constant. This effect is temporary and soon each of the new leaves will again be longer than its predecessor so that the curve resumes more or less its original trend (DE), until the plant is again cut (E) when the entire process is repeated. Thus, once cutting has started the leaf length increases more slowly than it would have done had the plant been left uncut. This slower increase is indicated by the line BF.

The length is an important characteristic of the sisal leaf. It determines the length

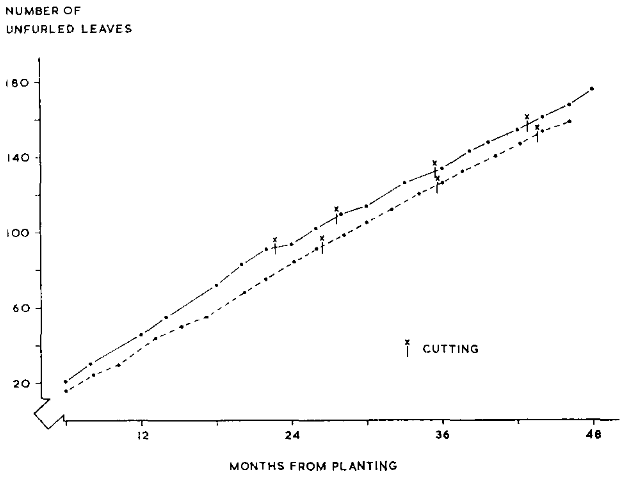

Fig. 2 Leaf production for sisal in two different trials during the first years since planting.

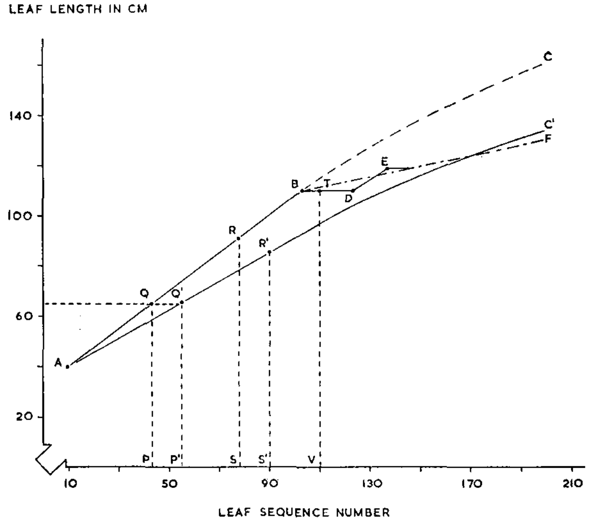

Fig. 3 Theoretical regression curves of leaf length on leaf sequence number for cut and uncut sisal. For explanation see text.

of the fibre obtained from it, and as the weight of a sisal leaf is proportional to the square of its length (Wilson, 1951) a long leaf means much more fibre than a short one. Cut leaves shorter than 60 cm have no economic value. Allowing for the tip thorn which is removed upon cutting, and for the lower end which is not cut, a leaf on the plant of 65 cm or longer is regarded as cuttable. Normally cutting starts when the first cuttable leaves start withering. Considering that a first cut requires a yield of about 35 leaves per plant (Lock, 1962: p. 125) whereas 25 leaves are to be left on the plant, then the area PQRS in Fig. 3 indicates the leaves harvested at first cut. None of these leaves is longer than 90 cm. The second cut will include the 25 leaves left at first cut, plus another 5 or 10 unfurled since the first cut was taken (SRBTV in Fig. 3). As a result of the stunting effect of the first cut the length of the longest of these leaves equals at the most the length of the last unfurled leaf at the time of first cut. The other leaves are shorter.

If the rate of increase in leaf length is less than 0.75 cm per leaf the regression curve will be flatter (e.g. AC′). This has serious consequences for the yield. Firstly, the first cuttable leaf will have a higher sequence number. This means that with a fixed leaf potential less leaves will be harvested over the entire life cycle. Secondly, the first cut comprises relatively shorter leaves (P′Q′R′S′ as opposed to PQRS) and so will all subsequent cuts. In other words the fibre yield over the cycle will be less than when longer leaves were produced.

Apart from the fibre yields being lower the fibre from short leaves is also more costly. In East Africa a cutter's task consists in cutting a fixed number of leaves irrespective of their size. Since short leaves yield less fibre this means that more man days are required to obtain one ton of fibre from short leaves than from long leaves. The importance of this becomes clear when it is considered that cutting is one of the major items in the cost of producing sisal fibre.

Related Agave species and Agave hybrids

Agave species

The regular growth pattern as described for sisal is not characteristic for this agave only but also applies to other *Agave* spp. of the section Rigidae. Apart from leaf characteristics the species differ from each other in rate of leaf unfurling and in rate of increase in leaf length. Some data to illustrate this are presented in Table 1. From this table it can be seen that there is a tendency among these species for a high rate of leaf production to be associated with a low rate of increase in leaf length. In other words, species with a low rate of leaf unfurling are generally species with long leaves. *A. fourcroydes,* henequen, and *A. cantala,* cantala, the two other long fibre agaves of economic importance, are both characterised by a high rate of increase in leaf length. The same applies to *A. amaniensis.* On the other hand,

Table 1 Rate of leaf unfurling and rate of increase in leaf length for some Agave species of the section Rigidae.

Species	*Rate of leaf unfurling (leaves/month)*	*Rate of increase in leaf length (cm/leaf)*
A. amaniensis	4.4	1.15
A. angustifolia	11.2	0.18
A. bergeri	7.2	0.43
A. cantala	5.1	1.22
A. fourcroydes	3.0	1.51
A. lespinassei	7.0	0.78

A. angustifolia has a very low rate of increase in leaf length but a high rate of leaf unfurling.

Agave hybrids

A. amaniensis and *A. angustifolia* have formed the basis for the improvement of the long fibre agaves through breeding in Tanganyika. Many hybrids selected in the course of this work have been grown in comparative trials to test their yield potential, and detailed leaf counts and leaf measurements are available for most of these selections including hybrid no. 11648. The three earliest trials were planted from 1949 to 1952. They do not comprise hybrid no. 11648 which has been tested in its own series of trials.

The records for these hybrids show that their growth pattern is similar to that noted for sisal and other *Agave* spp. and that rate of leaf production and rate of increase in leaf length are very much varietal characteristics. The effect of cutting on leaf length as described for sisal is also observed for these hybrids. This is illustrated in Fig. 1 where the regression lines of leaf length on leaf sequence number are plotted for hybrid no. 11648 and sisal in the same comparative trial until after the second cut.

Hybrid no. 11648 produces leaves at twice the rate, and has a total leaf potential which is about three times that of sisal. It differs from sisal in that it has a lower rate of increase in leaf length than sisal. The data in Table 2 illustrate this. It should be added here that in these trials both clones were heavily manured which explains the above-average growth rates recorded for sisal.

In order to substantially increase the annual fibre yields it is essential that the ideal long fibre *Agave* hybrid has a much higher rate of leaf unfurling than sisal. In view of the earlier mentioned tendency among the *Agave* spp. in the section Rigidae of combining a high rate of leaf unfurling with a low rate of increase in leaf length, the question arises whether it is possible to breed for a hybrid which combines such a high rate of leaf unfurling with a rate of increase in leaf length which is comparable with that of sisal. To answer this question a number of hybrids have been examined for these two growth characteristics.

The earliest hybrids available are those in the three afore-mentioned comparative trials which included a total of 56 selections. These comprise hybrids derived from the cross *A. amaniensis* x *A. angustifolia* or its reciprocal (*amag* hybrids), plants derived from selfed *amag* hybrids (*amag.* S), from first back-crosses of *amag* and *amag.* S with *A. amaniensis* (*amag. am* and *amag.* S. *am*), and from second back-

Table 2 Rate of leaf unfurling and rate of increase in leaf length for uncut sisal and hybrid no. 11648 as recorded in three comparative trials planted in 1956, 1957 and 1958

	1956		*1957*		*1958*	
	sisal	*11648*	*sisal*	*11648*	*sisal*	*11648*
Rate of leaf unfurling (leaves/month)	4.2	8.9	4.3	8.6	4.0	7.8
Rate of increase in leaf length (cm/leaf)	0.88	0.38	0.90	0.42	0.80	0.36

crosses of *amag* hybrids with *A. amaniensis* (*amag. am. am*) (Doughty, 1965). In all three trials sisal was grown as the standard clone. Table 3 summarises the average rates of increase in leaf length for these hybrids. The clones are grouped in classes according to their relative rates of leaf unfurling. From these data it may be seen that there is a marked negative correlation between the two growth characteristics (r = — 0.82). For the individual trials the correlation coefficients are — 0.62, — 0.92 and — 0.88 respectively. None of these hybrids combines a high rate of leaf unfurling with a rate of increase in leaf length which approaches that of sisal.

The above growth characteristics were also calculated for 98 hybrids from inter-crosses of the earlier hybrids, and other back-crosses with *A. amaniensis* made in 1961 and 1962. Only those seedlings are considered which were ready for a first cut within 2 years from planting. The results (Table 4) again show a marked negative correlation between rate of leaf unfurling and rate of increase in leaf length (r = — 0.85). Among the more prolific hybrids no plant occurred with a rate of increase in leaf length comparable with that of sisal.

A third group is formed by 133 selections derived mainly from inter-crosses of the earlier hybrids made in 1957 and 1958. The data as summarised in Table 5 refer to individual plants. These results too show a negative correlation between the two growth rates but the correlation is not as marked as for the above hybrids (r = — 0.49). Among the more prolific types there are a number of plants that have a rate of increase in leaf length which lies above that of hybrid no. 11648. Only one

Table 3 Mean rate of increase in leaf length for the hybrid clones in the comparative trials planted in 1949, 1950 and 1952. Clones grouped in classes according to their rate of leaf unfurling as compared with that of sisal. Data refer to period from planting to first cut.

Relative rate of leaf unfurling (sisal = 1.0)	*Mean rate of increase in leaf length (cm/leaf)*		
	1949	*1950*	*1952*
0.5—0.9	—	0.73	0.90
1.0—1.4	0.55	0.47	0.64
1.5—1.9	0.45	0.28	0.49
2.0—2.4	0.37	0.27	0.27
2.5—3.0	0.36	—	0.23

Table 4 Mean and maximum rate of increase in leaf length, and rate of leaf unfurling corresponding with this maximum rate of increase in leaf length for hybrid plants from crosses made in 1961 and 1962. Plants grouped in classes according to their rate of leaf unfurling. Data refer to period from planting to first cut.

Actual rate of leaf unfurling (leaves/month)	*Rate of increase in leaf length (cm/leaf)*		*Rate of leaf unfurling corresponding with max. rate of increase in leaf length*
	mean	*maximum*	
3.0— 3.9	0.65	0.72	3.9
4.0— 5.9	0.45	0.64	4.5
6.0— 7.9	0.29	0.45	6.3
8.0— 9.9	0.23	0.31	8.5
10.0—10.9	0.19	0.20	10.1

Table 5 Mean and maximum rate of increase in leaf length, and rate of leaf unfurling corresponding with this maximum rate of increase in leaf length for hybrid plants from crosses made in 1957 and 1958. Plants grouped in classes according to their rate of leaf unfurling. Data refer to period from planting to first cut.

Actual rate of leaf unfurling (leaves/month)	*Rate of increase in leaf length (cm/leaf)*		*rate of increase in corresponding with max. Rate of leaf unfurling leaf length*
	mean	*maximum*	
4.0— 5.9	0.53	0.73	5.7
6.0— 7.9	0.35	0.51	7.1
8.0— 9.9	0.30	0.71	8.5
10.0—11.9	0.20	0.33	11.3
12.0—14.0	0.16	0.23	12.6

of these hybrids approaches sisal in this respect, but its leaf characteristics are such that this plant is not acceptable as a long fibre agave.

Discussion and conclusions

The markedly regular growth pattern as exhibited by the agaves makes it possible to describe their vegetative growth by two characteristics: rate of leaf unfurling and rate of increase in leaf length. Both largely determine the performance of these plants when grown for their fibre, especially during the first years after planting, although other characteristics as fibre percentage, leaf weight and shape are important as well. Annual fibre yields are directly correlated with the rate of leaf unfurling, and for quick economic returns it is essential that the plant grows fast both in terms of leaf number and leaf length. The period from planting to first cut, the immature period, is the most expensive phase in the growing of the long fibre agaves. There are no returns and a high standard of crop husbandry is required to keep this period as short as possible. The first cut comprises short and thus light leaves which means costly fibre. Returns remain therefore small until leaf length has increased such that the number of leaves required for the production of one ton of fibre is sufficiently reduced. Under normal conditions, the economically important long fibre agaves sisal, henequen and cantala, reach this stage at the second cut because of their rate of increase in leaf length. In view of this it is highly desirable that an *Agave* hybrid which is to replace one of these long fibre agaves resembles the latter in this respect. A lower rate of increase in leaf length will mean an extra number of short leaves. It does not necessarily result in a longer immature period providing the product of rate of leaf unfurling and rate of increase in leaf length is not smaller than that for the fibre agave it replaces. If the rate of leaf unfurling is such that this product is greater it may mean a shorter immature period, but this does not offset the greater number of relatively short leaves produced before the leaves attain a reasonable length. A low rate of increase in leaf length also means more leaves shorter than 60 cm which have no economic value at all. Moreover, such leaves are produced at the expense of the plant's leaf potential which has to be relatively large in order to offset this loss. On the other hand, a high rate of increase in leaf length and a high leaf number potential could lead to leaves longer than 150 cm. As very long leaves are difficult to handle and to process, it would be essential that the rate of increase in leaf length of such a plant should drop when the leaves have attained the desired length. Such a drop could be induced by overcutting (Lock, 1962: p. 143). An improved, i.e. high-yielding, long fibre agave should have a high rate of leaf unfurling and a high potential leaf number. The species *A. angustifolia,* which is outstanding for these two qualities (Doughty, 1938), has been used for the improvement of the long fibre agaves through breeding. Although it has been possible to combine a high rate of leaf unfurling and a high leaf number potential with some desirable characteristics of *A. amaniensis,* virtually all hybrids derived from this cross with a high rate of leaf unfurling also have a low rate of increase in leaf length. The negative correlation between these two growth characteristics as observed for the *Agave* spp. also appears to apply to the selected hybrids from the cross *A. amaniensis* x *A. angustifolia.* Among nearly 300 hybrids examined only one plant was found with the ideal combination, but undesirable leaf characteristics render this hybrid unacceptable as a long fibre agave. If it is considered that the ideal long fibre agave is to fulfil various conditions (see Lock, 1962: p. 252) the chances of obtaining this ideal plant seem remote. As a high rate of leaf unfurling is an essential condition for improved annual fibre yields, it may well be that a large number of short leaves during the first few years after planting has to be accepted as virtually unavoidable. However, a high leaf number potential means that leaf length can continue to increase so that eventually long leaves are produced. The experience with hybrid no. 11648, which has a low rate of increase in leaf length and a high leaf number potential, confirms this. In the later cuts this plant produces longer and heavier leaves than sisal thus partly offsetting the disadvantage of the many short leaves during the first years. Although the rate of increase in leaf length is to some extent affected by soil fertility, a low rate as observed in hybrid no. 11648 is inherent in the plant. The problem of the many short leaves produced by this hybrid during the first years cannot therefore be overcome by lowering the plant population as suggested by Lock (1962, p. 256).

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