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Economic Aspects of Browse Development

The economic viability of browse plantations in tropical Africa, a study following the Symposium on Browse in Africa, convened by the International Livestock Centre for Africa in April 1980.

International Livestock Centre for Africa
P. O. Box 5689, Addis Ababa Ethiopia.

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Editorial

Amongst the various constraints on the growth of animal production in the arid and semi-arid zones of tropical Africa, those associated with feed resources play an important part, with the latter reaching inadequate levels in terms of both quantity and quality for over half the year. These constraints become even more serious as stocking rates on rangeland increase. Grazing land suffers degradation, and when a change for the worse in rainfall patterns occurs, disaster can result.

Trees and bushes can play a fundamental role in the supply of feed resources. Their leaves, fruit and pods provide feed for both domestic and wild animals, especially during droughts or seasonal periods of nutritional stress. They also help to prevent soil erosion and desertification, form an important part of the nutrient cycle, and provide a source of energy as well as timber. Tree- and bush- dominated grazing land contributes significantly to animal production in Australia, the western USA, Mexico, Latin America and various other parts of the world, including the Middle East, India, North and southern Africa.

Browse is also used as a supplementary feed resource in the pastoral production systems of tropical Africa. However, little has yet been done to evaluate its potential systematically, and very little is known about most of the technical and socio-economic problems which browse production may raise. It was for this reason that at Addis Ababa, in April 1980, ILCA convened a symposium on browse in Africa, with a view to assessing the state of knowledge on this topic. Forty-seven scientists and experts attended the meeting, during which more than 50 papers were presented and discussed. These papers will be collected and published together in the near future. The collection will also contain a further paper analysing the economic feasibility of browse tree and shrub plantations in Africa. This paper was prepared by Dr. H.N. Le Houérou and Mme C. de Montgolfier-Kouévi, using information presented at the symposium as a basis. It is presented in this issue of the ILCA Bulletin, subject to some alteration so that the geographical range covered is restricted to tropical Africa.

PROGRAMME OF THE SYMPOSIUM

	SESSION No.	EVENT	SPEAKER
		Coordinator: H.N. Le Houérou	
		INTRODUCTION	
		Welcome address	D.J. Pratt
		Business session	
		INTRODUCTORY PAPER	
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	7	Methods of measuring primary production of browse	J.C. Bille
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	10	Utilization and management methods for browse (native and plantations)	J. Piot
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	11	Socio-economic constraints to the use of browse in development programmes	N. Dyson-Hudson
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	13	Integration of browse in pastoral and agropastoral production systems in Africa	B. Toutain and G. Boudet
April 11		**RESEARCH NEEDS**	
	14	Gaps in knowledge and research priorities	H.N. Le Houérou
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April 12	15	Summary of contributions and discussions. Proposals for the publication of a state of knowledge reports on browse in Africa. Proposals for an international cooperative programme	

ECONOMIC ASPECTS OF BROWSE DEVELOPMENT

Browse tree and bush plantations have an undeniable value in countries where labour is plentiful and cheap. In addition to supplying wood or other products such as gum arabic they provide livestock in the arid and semi-arid zones with feed supplies to cover the bridging period and during times of drought, often with a high protein value. They help to stabilize animal production without in any way competing with food or forage crops, which they may even benefit. Since they can be planted on marginal land which cannot be used for crops (sand dunes, steeply sloping land, rocky soil, land subject to flooding and soils with a high salt content, etc.), browse trees and bushes play an important part in protecting valley slopes and stopping erosion. Other species can be grown on cultivated land, helping to improve crop yields by supplying soil nutrients, especially nitrogen.

For these reasons the cost price of a feed unit (FU) produced from browse trees and bushes is probably lower than one produced from most of the concentrates used as animal feed. The cheaper forms of concentrate, such as cereal bran, urea and molasses, are in any case only available in limited quantities in specific areas, so that transport costs raise prices considerably outside the immediate production area. Their contribution to animal feeds in tropical Africa will be limited for many years to come, if not actually insignificant, whereas a deliberate policy to promote browse could not only improve animal nutrition but also help offset the shortage of fuel supplies (by producing firewood), at the same time as maintaining soil fertility and productivity.

Using experimental cases drawn from the existing literature, it therefore seemed relevant to undertake an evaluation of the feed resources which might be obtained by planting browse trees or bushes. Our aim has been to assess the economic feasibility of such plantations and to evaluate, or at least attempt to evaluate, the cost price of the animal feed which could be produced under relatively extensive conditions, in other words using a minimum of inputs.

THE METHODOLOGY USED

About 50 different species have been used for browse plantations in Africa, mostly in northern Africa and the Republic of South Africa. Experiments have also been carried out in tropical Africa, mostly involving *Acacia senegal* and *A. albida*. The methods used depend on the species, the technology available to users, and also on non-technical factors such as labour costs. Some species can be grown by direct sowing, either manual or mechanical, as is the case for several varieties of *Atriplex, Acacia* and *Artemisia,* as well as tree lucerne and others. Other species, such as the phyllodineous acacias, *Atriplex nummularia* and *Acacia cyanophylla,* have to be raised in the nursery, and the young stocks are subsequently planted out in the field. This method mainly applies to exotic species and/or arid environments where rainfall is unreliable and watering is necessary during the early stages. Planting density depends on many factors, including soil conditions, rainfall, species and the intended management method. It may vary from 20-200 trees per ha ,up to 4000-5000 bushes. In the case of the latter, plant spacing is geared to accessibility for livestock where direct browsing is planned, or to harvesting requirements.

Investment and operating costs

Experimental data on plantation establishment costs are available, but unfortunately they are not consistent and do not always appear meaningful. They cover establishment by direct sowing or by raising plants in the nursery before planting out in the field. Although they refer to plantations launched in many different parts of the world, only data relating to experiments carried out in Africa are dealt with here, with occasional reference for the purposes of comparison, to experience elsewhere. This approach led to the impression that establishment costs for these plantations were sufficiently uniform to be representative of conditions in tropical Africa as a whole. Establishment costs include soil preparation, water and soil conservation where necessary, and maintenance, consisting of weeding and ploughing before the productive period begins. To a great extent they depend on labour costs, which account for 80% of total costs when soil preparation is almost entirely carried out manually. Mechanization does not bring any appreciable reduction in costs, which merely break down differently, with a greater burden on the trade balance of the country concerned. The salaries of technical staff are not taken into account, nor is the purchase price of the land used.

To the establisment costs should be added those of enclosures to protect the plants. Enclosures may consist of barbed wire fences or thorn hedges. The former are much more expensive than the latter, especially in tropical Africa where, according to such estimates as were available the cost price of barbed wire fencing is about US $ 3/metre, amounting to US

$ 450/ha to cover an area of 10 ha or so. The cost of a double-row thorn hedge, on the other hand, is estimated at US $ 150/ha, but hedges have to be planted 2 or 3 years before the plantation itself, so as to afford proper protection, a factor which prolongs the unproductive period of the land by this amount of time. Investment in enclosures, whether barbed wire or hedges, therefore constitutes an important entry and often a very substantial one in the overall establishment costs for a plantation. For this reason these costs have been systematically isolated in the calculations of cost prices and profitability carried out here.

Estimating operating costs has proved somewhat more problematic. Since very little information was available, these data have had to be estimated on the basis of a number of assumptions. It has been assumed, for instance, that since this type of enterprise is primarily extensive, operating costs largely consist of fixed costs (mainly those of patrolling the plantation) which are independent of production, the latter being governed by ecological factors such as soil type and aridity, or socio-economic factors affecting management. Nonetheless, it was also argued that although browse plants can theoretically be used without variable operating costs since the feed can be consumed on the spot by the animals, the offtake of wood implies cutting and transport costs which are directly linked to the level of output. This approach may have led to some underestimation of operating costs, especially for plantations which were deemed to have the benefit of good management.

Income

In several cases where reliable data were lacking production was estimated on the basis of different assumptions in relation to yield, so that management differences could be taken into account and profitability thresholds also determined, so long as the range of yields adopted was felt to correspond to what could theoretically be achieved under extensive conditions. Estimating the value of production also caused complications, owing to the difficulty of establishing shadow prices for animal feeds. Shadow prices have important implications for calculating the internal rate of return (IRR), the factor under consideration here. Generally speaking the price of livestock feeds depends on their energy value (measured in forage units - FU - or any other unit directly or indirectly indicating the number of calories contained in the feed) and their protein content (measured in digestible protein - DP - per kg of feed). On the basis of these two factors and of market prices for the main livestock feeds (cereal brans, oil-cakes, meat meal), the prices per FU and per kg of DP were estimated to average US $ 0.16/FU and US $ 0.24/kg of DP during the year 1979. The relation between the two is unstable, since any movement in the relative prices of livestock feeds, especially between those with low and high protein contents, for example cereal brans against cakes, leads to distortion of the FU/DP price ratio (see Table 1) which may at times be considerable. Leaving aside the results for the years 1975 and 1976, which were affected by the sharp rise in cereal prices on the world market, the price per kg of DP is generally higher than the price per FU. The ratio was about 1.5:1 for the period 1975-1979, and for the year 1979 itself.

Table 1.

PRICE PER FU AND PER KG OF DP

	- in US cents -	
	FU	DP(kg)
World market[a]		
1975	14.1	10.1
1976	14.5	12.0
1977	13.3	28.6
1978	11.3	28.2
1979	15.6	24.0
Average 75/79	13.7	21.1
Tropical Africa		
Senegal (1979/80)		
1.[b]	0.4	48.0
2.[c]	16.0	16.0

a. Cereal brans/oilcakes and meat meal.

b. Wheat bran/soya cake

c. Wheat bran, molasses, *Acacia albida* pods and maize/groundnut cake.

Source: ref. 5 and 10 and various

Turning to the equivalent African prices, based on the example of cereal bran and cake prices, in Senegal in 1979/80, prices per FU and per kg of DP settle at levels quite different to those found on the world market. Protein in African countries has an extremely high value, while FU values are very low on account of low producer prices for cereal brans: 5-7 US cents per kg, as against 13.6 cents on the world market. These estimates, biased by the low prices of cereal brans as recorded at the place of production, do not appear truly representative of the real value of animal feeds in African countries. As noted above, when they are used cereal brans carry high transport costs which considerably increase their cost price to the final user.

Taking into account other animal feed products with a low protein content, such as molasses, *Acacia albida* pods and even maize, completely reverses the FU and DP price structure (US $ 0.16/FU and US $ 0.16 per kg of DP in Senegal for 1979/80), bringing it closer to that of the world market over the same period. In short, given the unreliability of FU and DP price estimates, the structure prevailing on the world market is probably the most representative. In the end, owing to the lack of other reliable data, it was therefore adopted as the basis for the FU and DP shadow prices used to calculate the IRR on planting browse trees and bushes in tropical Africa.

Adopting rather high FU and DP shadow prices is not very satisfactory, since in Africa livestock are fed at low cost on natural forage produced for the most part on land unfit for cultivation. However attractive from a financial point of view, browse plantations at the shadow prices identified by this method would probably have no economic applicability. An attempt has therefore been made instead to estimate FU and DP cost prices directly, assuming a given IRR, i.e. an opportunity cost of capital more easily determined on the basis of interest rates. Further difficulties arose in the attempt to identify two separate prices (per FU and per kg of DP), and also because browse trees and bushes can be used for several purposes, among which the production of wood at the same time as forage. For DP and FU prices a fixed structure at the level found on the world market in 1975-79 was assumed, giving a ratio of 1.5:1 between them.

In pastoral areas there is little incentive to produce wood alongside browse owing to the high cost of transport from produc-

tion to consumption areas[1/]. In the first place it was therefore assumed that browse trees and bushes are cultivated primarily for forage production, with wood being counted as a by-product with no market value, so that all investment and operating costs could be attributed to browse production. Thus the FU and DP cost prices are those which, for a given IRR, balance the discounted flow of income and expenditure resulting from the production of browse alone.

Secondly, however, it can be assumed that browse trees and bushes are cultivated for both wood and forage, which would mean that the various costs should be shared between the two activities. The breakdown of investment costs incurred for both types of enterprise was made to reflect the distribution of earnings from the two production alternatives, although this distribution is itself dependent on the shadow FU and DP prices being calculated[2/]. Operating costs, however, were broken down somewhat arbitrarily. Whatever the uncertainties to which it gives rise, this twofold approach allowed a range of FU and DP cost prices to be identified, which supplemented the estimates already carried out for IRR. Nonetheless, since the shadow price of wood is fairly low, the second part of the approach proved to have a fairly small impact on FU and DP cost prices.

Opportunity cost of land

Assessing the viability of browse tree and bush plantations raised one final issue, that of evaluating the opportunity cost of land. As already mentioned above, the purchase price of land was not included in the establishment costs of the plantation. In order to take this factor into account, the probable land use changes resulting from the establishment of the plantation have to be considered, especially as regards utilization of the grass stratum which had been previously used for feeding animals, with the result that investment and operating costs have to be analysed in terms of the incremental FU and DP production generated.

However, a further problem immediately arose: how to assess the value of the forage production lost, generally during the pre-development period, and specifically, what shadow price should be applied. In dry areas unsuitable for cropping the value of forage is generally thought to be very low, not merely because the opportunity cost of land is low but also because grass is relatively plentiful when it is available during the growing period, whereas the value of browse lies in its ability to supply extra feed during periods when livestock are undernourished. In other words, according to this theory the opportunity cost of land and the value of the unused grass stratum can be rated at zero.

This assumption fails to take into account the rising numbers of animals stocked on tropical African rangeland and the resultant growing scarcity of grass. For this reason the production of browse should not compete with grass but should complement it, if pastoral production systems are to survive. The same shadow prices were therefore adopted for both grass and browse plants. This decision theoretically implies underestimation of the IRR, although the impact appears fairly low. It is also open to the same objection as made above, that the shadow price of forage is too high given the conditions prevailing in tropical Africa, but the objection can be met with the same answer, that of estimating FU and DP cost prices on the basis of a given opportunity cost of capital, still assuming that the two prices are the same for grass and browse plants.

Simple types of management involving direct browsing were generally envisaged, although more sophisticated systems could have been imagined, involving deferred or rotational grazing or browsing, and implying lower stocking rates in the short term but improved yields in the long run. A more dynamic approach would also have taken into account the stabilizing effect of browse reserves on herd numbers during serious droughts. But an approach of this kind would have needed more reliable data than those available at present.

INTERNAL RATE OF RETURN AND COST PRICE

The plantations analysed below concern browse tree and bush species with highly variable production characteristics, so that the results obtained allow comparison between different combinations of enterprise - browse and wood, browse and gum, browse and improved crop yields - in different environments.

Atriplex plantations

Highly resistant to drought, *Atriplex* species can grow on heavy, salty or alkaline soils with an average rainfall of 150 mm per year. They do not adapt well in some arid tropical zones such as the West African Sahel, but on the other hand they seem well suited to conditions found in the dry zones of eastern Africa. They provide browse with a high crude protein (CP) content (15 to 25% of DM), and plantations can be directly grazed without incurring any specific management problems. The grass stratum can thus be used at the same time as the browse, as soon as the plantation reaches maturity. Finally, *Atriplex* plantations can also be used for producing wood, although its quality is rather poor and producer prices are definitely low owing to transport

1/ In Senegal the cost of acacia wood was around US $ 50/tonne in urban areas in 1980. On the other hand, *Pterocarpus lucens* wood was priced at under US $ 30/t in Niono, Mali, at the same time, after the seller had devoted between 24 and 30 hours to collecting it in the bush. Taking into account the opportunity cost of his labour and other outlays (depreciation of the donkey and cart used for transport), the cost price of wood in the bush would certainly not be over US $15-16/t. To avoid any risk of overestimation, this was the level chosen for the shadow price of wood (acacia) used in the IRR calculations.

2/ The following procedure was followed for investments: an initial breakdown of earnings using the shadow prices adopted for the IRR calculation, followed by a second breakdown on the basis of estimated average cost prices; this enabled a second estimate to be made, which was considered as final. As regards operating costs it was decided that all fixed costs (patrolling) could be attributed to forage production, while variable costs (cutting and transport of wood) were attributed to wood production.

costs. Wood yields from *Atriplex* plantations are broadly similar in terms of weight to the leaf production used for browse.

Investment costs for *Atriplex* plantations have been studied in various parts of the world. In the Norte Chico region of Chile, where annual rainfall averages 200 mm, establishment costs for plantations of *A. repanda, A. nummularia, A. semibaccata, Galena secunda* and *Mairena brevefolia* were estimated at US $ 200/ha (Benjamin, 1980), with browse production at 1000 - 2000 kg of DM/ha/year. The costs included anti-erosion banks, planting - usually by direct drilling - and enclosures. Establishment costs for nursery - started plantations of *Atriplex nummularia* and *A. halimus* were studied in Tunisia by Franclet and Le Houérou (1971) and in Israel by Orev (1962). Although carried out under very different experimental conditions, using manual planting in Tunisia and mechanized drilling in Israel, the two studies reach similar results: US $ 80/ha (40 - 50 man-days/ha) in Tunisia with *A. nummularia* in 1969, i.e. US $ 245 in 1980 prices[3/], and US $ 70/ha using *A. halimus* in Israel in 1962, i.e. a 1980 cost of US $ 220. On the other hand, Barrachette (1980) calculates investment costs at US $ 475/ha for a recent plantation of 2000 stocks/ha in Tunisia, with costs spread over a period of 2 years, counting US $ 400 for the first years and US $ 75 for the second. This was the estimate used in the present IRR calculations for tropical Africa. To these costs should be added those of enclosures amounting, as noted previously, to US $ 450/ha for barbed wire fencing and US $ 150/ha for thorn hedges covering an area of approximately 10 ha.

As the *Atriplex* wood is marketed, the management system consists of allowing the animals to browse the leaves directly whenever the branches are cut. As a result, operating costs primarily consist of patrolling the plantation, estimated at US $ 12/ha/year (4 man-days), and wood cutting, again estimated at US $ 12 for an output of 2.5 t of wood.

Atriplex plantations established either with plants raised in the nursery or by direct drilling reach maturity in 2 or 3 years. When properly managed, leaf and wood production could reach 2.5 to 5 t of DM/ha each during the development phase, between 4 and 7 years. Nevertheless, output was assumed to be well below this figure, so as to take into account lower management capabilities at smallholder level, and browse production levels between 1.25 and 5 t of DM/ha were adopted, i.e. between 500 and 2000 FU. On this basis wood cutting costs are estimated between US $ 6 and US $ 24/ha/year, according to the assumption with regard to production. The value of production has been estimated using the FU and DP prices shown in Table 1, derived from livestock feed costs on the world market in 1979 and amounting to US $ 0.16/FU and US $ 0.24/kg of DP, and acacia wood prices in tropical Africa[4/]. Owing to its inferior quality the costs of *Atriplex* wood have been estimated at half those of acacia species, amounting to US $ 7.8/t. Overall, the value of output varies from US $ 126 to US $ 504/ha (Table 2). It was also assumed that the plantation was established on grazing land producing about 200 FU/year with a DP content of 125 g/FU, i.e. having a value of US $ 38 on the basis of FU and DP shadow prices, and that the land cannot be grazed during the first 3 years of predevelopment, or the first 5 years when the plantation is enclosed with thorn hedges, in other words before it reaches maturity.

Table 2.

BROWSE AND WOOD PRODUCTION ON ATRIPLEX PLANTATIONS IN TROPICAL AFRICA

Per hectare	Production assumptions							
	1 (Years 5-20)		2 (Years 6-20)		3 (Years 7-20)		4 (Years 8-20)	
	Wood	Browse	Wood	Browse	Wood	Browse	Wood	Browse
DM(kg)	1250	1250	2500	2500	3750	3750	5000	5000
FU[a]	-	550	-	1000	-	1500	-	2000
DP(kg)[b]	-	150	-	300	-	450	-	600
Value during development period (US $)[c]	10	116	20	232	30	348	40	464

a. Based on a value of 0.4 FU/kg of DM

b. Based on a value of 300 g of DP/FU

c. Shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP and US $ 7.8/t of wood.

The IRR reaches at least 15% when browse and wood production are 2.5 t of DM/ha, and is still above 10% when output is equal to or above 1.25 t of DM/ha and no enclosure costs are included. When yields become more substantial the IRR is over 20%, and even reaches 30% without enclosures. The FU cost price at this level is only US $ 0.3 - 0.5/FU, with a 10% opportunity cost of capital, and US $ 0.4 - 0.8 for an IRR of 15%, a level well below the shadow price (Tables 3 and 4). According to the results in Table 4, the FU and DP cost prices are always higher than shadow prices if browse production is very low (500 FU), except when there are no enclosures and the opportunity cost of capital is 10%. When

Table 3.

INTERNAL RATE OF RETURN ON ATRIPLEX PLANTATIONS IN TROPICAL AFRICA[a]

- in % -

Production	Enclosures		
	No enclosure	Hedges	Barbed wire
500 FU	14.2	7.8	6.4
1000 FU	24.7	16.3	14.9
1500 FU	30.6	21.2	20.0
2000 FU	33.8	24.0	23.0

a. Project life of 20 years; Shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP and US $ 7.8/t of wood.

3/ Costs were re-evaluated using the UN index of unit values of manufactured goods exported by developed countries (UNCTAD, 1978/79).

4/ As estimated in footnote 1.

Table 4.

FU AND DP COST PRICES ON ATRIPLEX PLANTATIONS IN TROPICAL AFRICA [a]

- in US $/FU -

Enclosures	No enclosure		Hedges		Barbed wire	
IRR	10%	15%	10%	15%	10%	15%
Production: 500 FU						
without wood product.	0.13	0.19	0.21	0.33	0.23	0.33
with wood production	0.11	0.16	0.19	0.31	0.21	0.30
Production: 1000 FU						
without wood product.	0.07	0.10	0.11	0.16	0.12	0.18
with wood production	0.06	0.08	0.09	0.14	0.10	0.16
Production: 1500 FU						
without wood product.	0.05	0.07	0.08	0.11	0.09	0.13
with wood production	0.04	0.05	0.06	0.09	0.07	0.10
Production: 2000 FU						
without wood product.	0.04	0.06	0.06	0.09	0.07	0.10
with wood production	0.03	0.04	0.05	0.07	0.05	0.08

a. DP cost price is assumed to be 1.5 times higher than FU cost price ; project life is 20 years.

FU and DP cost prices are lower than shadow prices.

browse yields rise to 1000 FU/ha, FU and DP cost prices remain higher than shadow prices when the plantations are fenced with barbed wire and the IRR is 15%. Using thorn hedges instead slightly improves both IRR and FU and DP cost prices, but not very significantly in view of the difference in investment costs (a ratio of 1:3). The prolonged unproductive investment period largely offsets the savings achieved by not using barbed wire fencing. In all other cases cost prices are lower than shadow prices.

To sum up, *Atriplex* plantations in tropical Africa allow forage with a high nutritive value (owing to its favourable protein) to be produced at moderate cost as soon as yields are over 1000 FU/ha.

Acacia plantations

Acacia is a genus of the Leguminosae family, probably consisting of over 900 species which vary considerably in appearrance from low bush to tree and which are distributed almost throughout the semi-arid tropical zones of the world. Many of them adapt well to sandy environments and can be used for stabilizing sand dunes and protecting the environment, while others, such as *Acacia albida*, have long been grown in agropastoral systems, usually involving millet, or raised for the production of gum arabic, as in the case of *A. senegal*. About a dozen of these species are considered to produce leaves and pods which form an excellent quality forage, rich in protein and phosphorous although poor in glucides.

Acacia cyanophylla plantations

Acacia cyanophylla, as well as, to a lesser degree, other species related to the phyllodineous Australian acacias (*A. salicina, A. ligulata, A. cyclops, A. victoriae* and *A. pendula*), have been used in forestry for 40 to 60 years on many thousand hectares in North Africa from the humid coastal strip to the arid zone, mostly for fixing coastal sand dunes but sometimes those of the interior also. The browse output from leaves, branches and pods is somewhat higher than from *Atriplex*, and may reach 6 t of DM/ha on well managed plantations, although FU and DP yields are similar and slightly lower respectively (see Table 5) than those found on *Atriplex* plantations. Growth of the grass stratum may approach zero when the planting density is around 800 to 1000 bushes/ha. Wood production is high and its quality is better than *Atriplex*. The tree can be used by cutting and carrying, by direct grazing after trimming, or by direct browsing with periodic pruning. The impact of the various management methods is, however, little understood.

North African experience indicates that establishment costs for a plantation with

Table 5.

WOOD AND BROWSE PRODUCTION ON ACACIA CYANOPHYLLA PLANTATIONS

Per hectare	Production assumptions 1 (Years 5-20)		2 (Years 6-20)		3 (Years 7-20)		4 (Years 8-20)	
	Wood	Browse	Wood	Browse	Wood	Browse	Wood	Browse
DM(kg)	1500	1500	3000	3000	4500	4500	6000	6000
FU[a]	-	500	-	1000	-	1500	-	2000
DP[b]	-	100	-	200	-	300	-	400
Value during development period (US $)[c]	23	104	47	208	70	312	94	416

a. Based on a value of 0.33 FU/kg of DM

b. Based on a value of 200 g of DP/FU

c. Shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP and US $ 7.8/t of wood.

a density of 1000 bushes/ha require about 125 man-days/ha, corresponding to US $ 600/ha spread over 2 years, with US $ 550 for the first year and US $ 50 for the second, to which the usual enclosure costs should be added. Operating costs are fairly low when direct grazing is used, estimated, like those for *Atriplex*, at US $ 12/ha for patrolling and US $ 12 for cutting and transporting 2.5 t of wood.

Production of browse and wood can generally begin after 3 years, building up gradually to full development. Expressed in terms of DM, wood and leaf production are identical, such that 3 kg of wood are produced for each FU. A properly managed plantation above the 200 mm isohyet can produce 3000 kg of DM in phyllodes and 3000 kg of wood per ha and per year. However, four different assumptions as to production have been chosen, so as to represent management systems of varying efficiency (Table 5). On this basis, and taking into account the shadow prices of acacia browse and wood, the value of output varies between US $ 127 and US $ 510 per ha, with 20% attributable to wood and 80% to browse. It has also been assumed that since the grass stratum would be unable to grow at this plant density the value of the original grazing is lost throughout the development period, amounting to US $ 38/ha on the basis of an output of 200 FU with a DP content of 125 kg/FU.

At equal production levels, and despite a higher shadow price of wood, IRR levels are much lower than for *Atriplex* plantations. They are below 5% when browse production is 500 FU/ha, with FU and DP cost prices between two and six times higher than shadow prices, and are still under 10% in enclosed plantations when it reaches 1000 FU (3 t of DM/ha), a level roughly equivalent to that achieved elsewhere on properly managed plantations. The IRR remains less than 20% when production reaches about 6 t of DM per ha (2000 FU), unless no enclosures are used (Table 6). The FU and DP cost prices at this level are fairly low for a 10% opportunity cost of capital, especially if wood is produced at the same time as browse. When browse production is a around 1000 FU/ha the FU and DP cost prices are only lower than shadow prices when certain favourable conditions are also fulfilled, namely when IRR is 10%, and no enclosures costs are incurred or both wood and forage are produced (Table 7).

Table 6.

IRR ON ACACIA CYANOPHYLLA PLANTATIONS IN TROPICAL AFRICA[a].

- in % -

Opportunity cost	FU cost price of US $ 0.16			Zero		
Enclosure	no enclosure	hedges	barbed wire	no enclosure	hedges	barbed wire
500 FU	3.8	0.1	0.1	11	7	5
1000 FU	14.2	9.4	8.6	20	14	12
1500 FU	19.3	14.1	13.3	24	18	16
2000 FU	22.6	17.1	16.3	27	20	18

a. Project life of 20 years; shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP and US $ 15.6/t of wood.

Two factors explain these rather unpromising results. The first is the non-utilization of the grass stratum throughout the entire project life, while the second is the relatively high cost of investments (US $ 600/ha, as against US $ 475 for *Atriplex* plantations). If the impact of not using the grass stratum were ignored and a zero opportunity cost of land assumed, the IRR on *Acacia cyanophylla* plantations would approach that on *Atriplex*, although always remaining somewhat lower (see Table 6), and profitability thresholds would be fairly similar for the two. Browse cost prices would be lower than shadow prices if yields were 1000 FU/ha, except in the least favourable cases, and even when yields were 500 FU/ha and conditions at their most favourable, with no enclosure costs, IRR at 10% and

Table 7.

FU AND DP COST PRICES ON ACACIA CYANOPHYLLA PLANTATIONS IN TROPICAL AFRICA[a]

- in US $/FU -

Enclosures	No enclosure		Hedges		Barbed wire	
IRR	10%	15%	10%	15%	10%	15%
Production: 500 FU						
without wood production	0.44	0.69	0.84	2.38	0.66	1.11
with wood production	0.34	0.60	0.75	2.23	0.57	1.02
Production: 1000 FU						
without wood production	0.15	0.23	0.23	0.39	0.24	0.37
with wood production	0.11	0.18	0.18	0.33	0.18	0.31
Production: 1500 FU						
without wood production	0.10	0.15	0.15	0.23	0.16	0.24
with wood production	0.06	0.10	0.10	0.18	0.11	0.19
Production: 2000 FU						
without wood production	0.08	0.12	0.11	0.18	0.12	0.18
with wood production	0.04	0.09	0.07	0.13	0.08	0.14

a. DP cost price is assumed to be 1.5 times higher than FU cost price; project life is 20 years.

FU and DP cost prices are lower than shadow prices.

Table 8.

FU AND DP COST PRICES ON ACACIA CYANOPHYLLA PLANTATIONS IN TROPICAL AFRICA, ASSUMING ZERO OPPORTUNITY COST OF LAND[a]

	- in US $/FU -					
Enclosures	No enclosure		Hedges		Barbed wire	
IRR	10%	15%	10%	15%	10%	15%
Production: 500 FU						
without wood production	0.19	0.26	0.25	0.35	0.30	0.42
with wood production	0.15	0.23	0.22	0.33	0.26	0.39
Production: 1000 FU						
without wood production	0.11	0.15	0.14	0.20	0.17	0.24
with wood production	0.07	0.11	0.11	0.17	0.13	0.20
Production: 1500 FU						
without wood production	0.08	0.11	0.11	0.15	0.12	0.18
with wood production	0.05	0.08	0.07	0.11	0.09	0.14
Production: 2000 FU						
without wood production	0.07	0.09	0.09	0.11	0.10	0.15
with wood production	0.04	0.05	0.05	0.09	0.06	0.11

a. Same assumptions as Table 7, but without production losses caused by non-utilization of grass stratum.

FU and DP cost prices are lower than shadow prices.

simultaneous production of wood and browse. On the other hand, if yields rose to the levels achieved on plantations with optimum management (1500 or 2000 FU/ ha), FU and DP cost prices would in most cases fall to fairly low levels (Table 8). Assumptions as to the value of the grass stratum therefore have a real impact only when browse yields are very low. However, when this is the case other factors, especially investment costs, weigh all the more heavily on the profitability of these plantations.

Phyllodineous acacia plantations

Hamel (1980) has carried out estimates on the Senegalese production of phyllodineous acacias from Australia (*Acacia holosericea* and *A. linaroides*), species which seem to have acclimatized successfully so far, although they have not been tested in the more demanding zones.

In this country the establishment costs of a plantation with a density of 1000 bushes/ha have been estimated at around US $ 500 to 600, a figure slightly below those for *A. cyanophylla* plantations. To this figure should be added the usual enclosure costs of US $ 450/ha for barbed wire fencing and US $ 150/ha for double-row thorn hedges. Operating costs have not been specified, but it can be estimated that they must be close to those previously adopted for *Atriplex* and *Acacia cyanophylla* plantations when direct grazing is used, namely US $ 12/ha for patrolling and US $ 12 for cutting and transporting 2.5 t of wood, i.e. US $ 20 per year for an output of 4 t of wood.

According to Hamel's assumptions, browse production can begin in the third year with output at 1250 kg of DM/ha, reaching 2000 kg during the fourth year and 2500 kg in the fifth year, while wood production is 2 t/ha/year. Using FU and DP shadow prices estimated respectively at US $ 0.16 and US $ 0.24, the value of output during the development period is US $ 332/ha. A lower production assumption than Hamel's has nevertheless been adopted, according to which browse and wood production are sustained at 1250 kg of DM and 2 t of wood per ha throughout the development period (Table 9). It has also been anticipated that non-utilization of the grass stratum during the pre-development period results in a primary production loss of 200 FU and 25 kg of DP with a value of US $ 38/ ha.

Although investment costs for barbed wire are very high, the IRR is over 15% for plantations with enclosures of this kind, while browse production is 2500 t of DM/ha (Table 10). It even reaches 20% when no enclosures at all are involved. As already observed, thorn hedges, although three times cheaper than barbed wire fencing, only marginally improve the

Table 9.

BROWSE AND WOOD PRODUCTION ON PHYLLODINEOUS ACACIA PLANTATIONS

Per hectare	Production assumptions			
	1[a] (years 3 - 20)		2[b] (years 5 - 20)	
	Wood	Browse	Wood	Browse
DM (kg)	2000	1250	4000	2500
FU[a]		500	-	1000
DP (kg)[b]		100		200
Value during development period (US $)[c]	62	104	124	208

a. Based on a value of 0.4 FU/kg of DM

b. Based on a value of 200 g of DP/FU

c. Shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP and US $ 15.6/t of wood.

Table 10.

IRR ON PHYLLODINEOUS ACACIA PLANTATIONS[a]

- in % -

Enclosures	Production assumptions	
	500 FU	1000 FU
Barbed wire	7.3	16.9
Hedges	8.7	19.5
No enclosure	16.0	28.9

a. Project life of 20 years; shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP and US $ 15.6/t of wood.

Table 11.

FU AND DP COST PRICES ON PHYLLODINEOUS ACACIA PLANTATIONS[a]

- in US $ -

Production	500 FU				1000 FU			
IRR	10%		15%		10%		15%	
Wood production	Yes	No	Yes	No	Yes	No	Yes	No
Barbed wire fences	0.20	0.26	0.27	0.35	0.09	0.14	0.13	0.19
Hedge	0.18	0.24	0.34	0.30	0.08	0.12	0.12	0.18
No enclosure	0.10	0.15	0.15	0.21	0.04	0.09	0.07	0.11

a. DP cost price is assumed to be 1.5 times higher than FU cost price.
FU and DP cost prices are lower than shadow prices.

IRR. When browse production is low (500 FU/ha) the IRR is below 10% for plantations with enclosures, and FU cost prices reach US $ 0.35 in the least favourable cases, when IRR is 15%, barbed wire fences are used and wood is not produced.

On the other hand, when enclosures are not used the IRP reaches 16% for this level of production. However, the FU and DP cost prices are above shadow prices if, for a 15% opportunity cost of capital, wood is not produced together with forage (Table 11). A similar situation is found - IRR above 15%, FU and DP cost prices higher than shadow prices - when, given a 15% opportunity cost of capital and production at 1000 FU/ha, the plantations are equipped with barbed wire fences or thorn hedges. In most cases where FU cost prices are lower than shadow prices, these tend to lie at about US $ 0.10-0.15/FU, only falling to below US $ 0.05/FU under the most favourable conditions, namely with IRR at 10%, no enclosure costs and production at 1000 FU/ha.

Acacia senegal plantations

The main production objective in plantations of *Acacia senegal* is gum arabic. Forage output is low, the tree only being available for browse outside the gum collection period, in other words at the beginning of the rainy and dry seasons, giving it only a marginal value as a supplementary source of feed during drought periods. Two plantations have been subject to particular study: both are found in the Sahel zone in areas receiving some 450 mm of rain per year, one in Senegal and the other in Sudan.

The M'Bidi plantation in Senegal covers several tens of hectares, at a density of 620 trees/ha. According to Koné (personal communication), establishment costs were probably about US $ 330/ha, spread over 4 years (US $ 240 during the first year and US $ 30 during the 3 following years). These costs do not include enclosures, estimated as usual at US $ 450/ha for barbed wire fences or US $ 150/ha for hedges. The El Obeid plantation in Sudan has, according to Seif el Din (personal communication), a density of 610 to 630 trees/ha, similar to the figure for M'Bidi in Senegal. However, establishment costs for this plantation, excluding enclosures, were estimated at under US $ 200/ha (as against US $ 330 in Senegal), spread over 2 years at US $ 160-180 for the first year and US $ 20 for the second. Apart from the usual patrolling costs estimated at US $ 12/ha, operating costs primarily concern the harvesting and transport of gum. They are estimated to average US $ 66/ha in Sudan, a figure thought to be representative of conditions throughout the region.

Gum production is estimated at 250 g/tree (155 kg/ha) from the fifth year onwards and over a period of 35 years, at the end of which the plantation has to be entirely renewed. The trees are therefore cut down and the wood is sold in bulk at the end of the project period. Browse production, consisting of leaves, can be estimated at 1 kg of DM of leaves per year, with a feed value of 0.33 FU/kg of DM, i.e. 200 FU/ha with a DP content of 200 g/FU. The annual value of production during the development period lies at

Table 12

BROWSE, WOOD AND GUM PRODUCTION ON ACACIA SENEGAL PLANTATIONS

Per hectare	Gum	Wood	Browse
In kg	155	18 600[a]	620[b]
In FU	-	-	200[c]
In DP			40[d]
Value during development period (US $)[e]	124	290	39

a. At the end of project life, based on 30 kg per tree

b. In kg of DM

c. Based on a value of 0.33 FU/kg of DM

d. Based on a value of 200 g of DP/FU

e. Shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP, US $ 15.6/t of wood and US $ 0.8/kg of gum.

Table 13.

IRR ON ACACIA SENEGAL PLANTATIONS[a]

- in % -

	Senegal	Sudan
Barbed wire	4.1	7.2
Hedges	5.6	7.0
No enclosure	10.5	13.2

a. Project life of 20 years.

US $ 163/ha, with the salvage value of wood when the plantation is cut down at the end of the project standing at some US $ 290/ha (Table 12). The grazing land taken up by the plantation cannot be used throughout the pre-development period, and the forage production lost during these first 5 years has been estimated at 150 FU/year with a protein content of 125 g of DP/FU.

The IRR, which is slightly higher for the El Obeid than for the M'Bidi plantation owing to lower investment costs, is under 10% when the plantations are equipped with enclosures and between 10 and 13% when no enclosures are used (Table 13). *A. senegal* plantations are primarily intended for gum production, and consequently it has been assumed that in contrast to the former cases browse production could take place at the same time as gum production, or at least be treated as a by-product of the latter. In this case the FU (or DP) cost price, designated the marginal cost price (Table 14), is the one enabling the discounted cash flow from net expenditure to be balanced when profits from the sale of gum are deducted.

According to the results in Table 14 the average FU and DP cost prices are always higher than shadow prices, even in the most favourable cases when no enclosure costs have to be included and when the opportunity cost of capital is 10%. The discounted cash flow resulting from FU gains and losses becomes negative when the plantations are hedged, owing to the longer unproductive investment period, during which the grass stratum cannot be used. Treating browse as a by-product of gum improves cost prices, which fall below shadow prices when the plantations are not enclosed and the opportunity cost of capital is 10%. The FU cost price falls in this case to US $ 0.10 and even to zero in Sudan, where lower investment costs mean that gum production by itself is enough to ensure financial equilibrium at this level of IRR. *A. senegal* plantations are thus only marginally attractive in terms of browse production.

Acacia albida plantations

Acacia albida is very widespread between sea level and 1800 m in the semi-arid and subhumid zones of tropical Africa. Unlike most deciduous tropical trees it loses its leaves during the rainy season and keeps them throughout the dry season. It is traditionally planted in millet, cowpea and groundnut fields in areas with an annual rainfall of 400 to 800 mm, forming part of an agricultural system used by several African peasant civilizations. Millet is cultivated between and beneath the trees, and the interception of light by the foliage during the growing season is negligible, so that shading has no effect on the crops growing at their foot. Also, as the leaves fall at approximately the same time as ploughing begins, most of them are ploughed into the soil and act as fertilizer, improving crop yields. It has been estimated that millet yields in fields planted with *A. albida* can be 2 to 2.5 times higher than yields in open fields without fertilizer. Under the conditions found in the semi-arid zones of West Africa this means that millet yields can increase from 500-800 kg/ha to around 1000-1500 kg/ha. In addition, pod production, reaching an average of 400 to 600 kg/ha/year, provides livestock with a protein-rich feed to supplement their roughage. *A. albida* pods were being sold at 45 CFA francs (US $ 0.21) per kg in Senegal in 1980, around US $ 0.30/FU (1 kg represents 0.7 FU).

A. albida generally lives to about 80 years. The tree becomes productive only after 15 years and is adult at the age of 25. Fruit production is therefore zero between 0 and 15 years, then gradually increases. The fertilizer effect, which also increases gradually, does not begin to show before the trees reach 10 to 15 years, and probably takes about 10 years thereafter to reach its full extent, at about 25 years when the tree is mature. The final plant density of *A. albida* is

Table 14.

FU AND DP COST PRICES ON ACACIA SENEGAL PLANTATIONS[a]

- in US $ -

	Senegal		Sudan	
	Average[b]	Marginal[c]	Average[b]	Marginal[c]
IRR of 10%				
. barbed wire fences	0.38	0.90	0.35	0.70
. hedges	d	d	d	d
. no enclosure	0.25	0.10	0.23	e
IRR of 15%				
. barbed wire fences	1.92	4.00	1.68	3.40
. hedges	d	d	d	d
. no enclosure	0.95	1.10	0.78	0.40

a. DP cost price is assumed to be 1.5 times higher than FU cost price.

b. Simultaneous production of gum and browse.

c. Browse considered as a by-product of gum production.

d. Discounted cash flow of FU and DP lost is higher than that from browse production.

e. Gum production alone is enough to provide financial equilibrium at an IRR of 10%, so that the FU cost price can be rated at zero.

FU and DP cost prices are lower than shadow prices.

usually 10 to 50 trees/ha, but given the length of the production cycle it is preferable to have a higher density at the outset in order to meet losses, with subsequent elimination of some of the trees as they reach maturity.

Planting costs have been estimated at US $ 1 per plant, i.e. US $ 0.55 for planting as such and US $ 0.03/tree/year for maintenance until the trees become productive, that is until aged about 15 years. These figures add up to a total of US $ 100 for an initial planting density of 100 trees/ha, US $ 55 for the first year and US $ 3 for the next 14 years, to which should be added any enclosure costs (US $ 450/ha and US $ 150/ha respectively, according to whether barbed wire or hedges are used). No further costs are incurred, apart from collecting the pods and cutting the branches when pruning, but these were considered negligible.

On the basis of the yields estimated above and of shadow prices of US $ 0.16/FU and US $ 0.24 per kg of DP, somewhat lower than the price for pods quoted on local markets in 1980, the value of pod production is US $ 73/ha between years 15 and 24 and US $ 146/ha from year 25 onwards. Wood production is very low, consisting of the sale of the 50% of trees eliminated after 20 years. On the other hand, the impact on crop yields is thought to be substantial with as already noted, at least twofold increases taking place within 10 years, between years 15 and 25 (Table 15).

Despite the length of the production cycle and the delay before *A. albida* plantations become productive, the IRR is generally higher than 10%, except when the plantations are supplied with barbed wire fencing. It is even close to 20% when no enclosures are used (Table 16). This result is astonishing, if the very long-term impact on crop and animal production is taken into account, although this positive aspect has hardly any impact on IRR when the depreciation period is extended to 80 years. The reasons why the Sultan of Zinder, in Niger a century or so ago, decreed that anyone cutting down an *A. albida* tree would himself be decapitated can easily be understood.

Since the value of a cash flow often becomes negligible after 30 years, the FU cost price calculation (Table 17) has been limited to a period of this length, although the actual life of *A. albida* is 80 years. Over 30 years, browse production alone is enough to balance income and expenditure when no investment is made in enclosures, even with a 15% opportunity cost of capital. Taking into account the improvement in agricultural productivity lowers the FU and DP cost prices to below the shadow price when plantations are provided with thorn hedges (but not barbed wire fences) and the opportunity cost of capital is 10%. In all other cases the FU and DP cost prices are well above the shadow prices adopted for calculating IRR. In the most favourable cases - no enclosure costs and a 10% opportunity cost of capital - the FU cost

Table 15.

IMPACT OF ACACIA ALBIDA PLANTATIONS ON BROWSE, WOOD AND CROP PRODUCTION

Per hectare	Browse		Crops		wood
	Years 16 - 25	25 years	Years 16 - 25	25 years	20th year
Production (kg)	500[a]	1000[a]	60[b]/year	600[b]	5000[c]
FU	350[d]	700[d]	-	-	-
DP	70[e]	140[e]	-	-	-
Value during development period (US $)[f]	73	146	12/year	120	78

a. DM, based on production of 5 kg of DM per tree between years 16 and 20 (100 trees), 10 kg between years 20 and 25 (50 trees) and 20 kg after 25 years.

b. Based on a doubling of yields in 10 years.

c. Based on 100 kg per tree eliminated.

d. Based on a nutritive value for pods of 0.70 FU/kg of DM.

e. Based on a value of 200 g of DP/FU.

f. Shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP, US $ 0.20/kg of millet/sorghum

Table 16.

IRR ON ACACIA ALBIDA PLANTATIONS[a]

- in % -

Enclosure	30 years[b]	80 years[b]
Barbed wire	8.2	10.1
Hedges	11.2	13.0
No enclosure	19.	19.9

a. Shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP, US $ 0.20/kg of millet/sorghum and US $ 15.6/t of wood.

b. Project life.

Table 17.

FU AND DP COST PRICES ON ACACIA ALBIDA PLANTATIONS[a]

- in US $ -

Enclosure	IRR of 10%		IRR of 15%	
	With improved crop yields	Without improved crop yields	With improved crop yields	Without improved crop yields
Barbed wire	0.28	0.42	0.91	1.03
Hedges	0.09	0.18	0.30	0.44
No enclosure	0.03	0.06	0.10	0.15

a. DP cost price is assumed to be 1.5 times higher than FU cost price; project life is 30 years.

FU and DP cost prices are lower than shadow prices.

price is US $ 0.03, or US $ 0.06 subtracting the improvement in crop yields.

Prosopis plantations

Although they have been more widely studied and are therefore better understood, *Atriplex* and acacia are by no means the only species used for livestock feeds in tropical Africa. Others with characteristics not fundamentally different from those analysed above can be cited, amongst which *Prosopis* spp., which closely resemble acacias in terms of the nutritive value of their leaves, branches and pods, although they tend to be less rich in protein (approximately 100 g of DP/FU). *Prosopis* spp. can also be used for wood production. Several varieties have been grown for browse in various arid zones throughout the world, especially *P. chilensis* and *P. juliflora* in the arid tropics of Africa and the Middle East. *P. cineraria* in Asia and *P. tamarugo* in Chili. In the latter country some 30 000 ha of *P. tamarugo* have been planted in the northern desert, with a density usually around 100 to 120 trees/ha. According to Robertson (1980), establishment and maintenance costs during the pre-development period were US $ 0.32 per plant, i.e. US $ 32/ ha for a density of 100 trees, while browse yields were 7 t/ha/year.

In tropical Africa a plantation of *P. juliflora* and *Parkinsonia aculeata* has been established in an area of the Cape Verde Islands receiving 100 to 300 mm of rain per year. According to Sabra (personal communication) it cost about US $ 0.526 per plant, in other words US $ 210/ha for an average density of 400 trees per ha, which is far higher than the Chilian example just cited. The costs were spread over 2 years, at US $ 150 for the first year and US $ 60 for the second. They include raising the plants in the nursery and transporting them to the planting site, soil preparation, digging of holes, water conservation measures, and finally, watering after planting out. No investment costs for enclosures are included. Operating costs are evaluated at US $ 5.5/ha during the development period.

Table 18.

BROWSE AND WOOD PRODUCTION ON PROSOPIS AND PARKINSONIA PLANTATIONS

Per hectare	Wood	Browse
DM (kg)	1500	1000
FU[a]	-	350
DP[b]	-	35
Value during development period (US $)[c]	18.7	64.5

a. Based on value of 0.35 FU/kg of DM

b. Based on value of 100 g of DP/kg of DM

c. Shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP and US $ 15.6/t of wood; development period is from year 6 to year 20.

Table 19.

IRR ON PROSOPIS PLANTATIONS[a]

- in % -

Enclosure	IRR
Barbed wire	9.6
Hedges	12.4
No enclosure	20.9

a. Project life of 20 years; shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP and US $ 15.6/t of wood.

The minimum production estimated in preliminary studies (measurement of primary production and evaluation of secondary production) was around 2 t of DM, of which 1 t was actually consumable, i.e. 350 FU/ha or 0.35 FU/kg of DM between the sixth and twentieth year of the project (Le Houérou, 1980; Lepape, 1980). Wood production can be estimated at 1200 kg of DM/ha/year, i.e. 13 kg per tree. Production during the development period can therefore be valued at US $ 83/ha (Table 18). It has also been assumed that the production losses due to non-utilization of the grass stratum during the pre-development period amount to 100 FU/ha/year with a DP content of 125 g/FU.

Owing to the fairly low establishment costs, the IRR is higher than 20% when the plantation is without enclosures, falling to somewhat less than 10% when barbed wire fences are used and 12% for thorn hedges. Given the relatively low production levels possible in the arid zone, installing enclosures, especially barbed wire, would remove much of the financial attractiveness from *Prosopis* plantations. Average FU and DP cost prices, often higher than the shadow prices, only fall to under US $ 0.10/FU (or US $ 0.05) when plantations are left without enclosures and the opportunity cost of capital is 10% (Tables 19 and 20).

Table 20.

FU AND DP COST PRICES ON PROSOPIS PLANTATIONS[a]

- in US $/FU -

IRR	IRR of 10%		IRR of 15%	
Wood production	Yes	No	Yes	No
Barbed wire fence	0.17	0.19	0.29	0.32
Hedges	0.12	0.15	0.23	0.26
No enclosure	0.05	0.08	0.09	0.12

a. DP cost price is assumed to be 1.5 times higher than FU cost price.
FU and DP cost prices are lower than shadow prices.

Leucaena plantations

Leucaena leucocephala is a leguminous tree of central American origin, found only in the subhumid tropics between 600 and 1800 mm of rainfall. It can be grown for both wood and browse. It gives not only a browse product of high quality, with a protein content similar to that of lucerne (25% CP), but also a high yield, reaching 20 t/ha/year. *Leucaena*

nonetheless contains a toxic amino acid, mimosine, which limits the proportion it is advisable to include in the feed ration of ruminants to a maximum of 30%, expressed in DM.

A project involving small plantations managed by peasants was launched in Malawi during the 1970s in order to boost the national production of high percentage concentrates. According to Beale (1980), investment costs can be estimated at US $ 272-318/ha, of which US $ 93 to 151 were devoted to the enclosures deemed necessary to protect the plants from damage by goats. However, these costs would probably have been considerably reduced (perhaps by 50%) if large-scale plantations had been involved, allowing substantial economies of scale, especially for enclosures. Operating costs were estimated at US $ 66/ha/year for a production of around 2 to 3 t of DM/ha. The leaves are purchased from producers at US $ 0.08/kg of DM, while the wood is not sold commercially, being used for drying the leaves. The sale of the latter shows a return of US $ 160 to 240/ha/year for the smallholdings financed by the project.

Available data were not sufficient to calculate the IRR and FU and DP prices using the same approach as for the other plantations. However, in the feasibility studies *Leucaena* leaves, as a cash crop, were considered the best production alternative, allowing small farmers to make a net profit of US $ 153/ha, whereas under local conditions profits from mixed farming are barely over US $ 120/ha.

lishment costs can very nearly double when the plantation is equipped with barbed wire fencing.

Evaluating production also posed a number of problems. The yields of browse trees and bushes are less well understood under tropical African conditions, so that sometimes several different levels of production have to be assumed in order to cover the range of yields possible at given levels of technology. To this initial cause of uncertainty may be added the further difficulty of estimating forage shadow prices. The criterion adopted, prices on the world market, has certain drawbacks since the resulting shadow prices are fairly high given animal feed conditions in tropical Africa. Naturally the prices adopted have some impact on the profitability of the operation under study, so that the world market price is probably only applicable if browse plants are thought of as a supplementary feed supply to replace concentrates during a drought period.

PROFITABILITY THRESHOLDS

It is difficult to throw very much light on the economic value of browse tree and bush plantations owing to the unreliable nature of the data used for the IRR calculations. The most consistent estimates are those relating to operating costs, but this is because they were carried out by the present authors owing to the lack of concrete information available elsewhere. In general terms it was assumed that these costs were fairly low owing to the extensive nature of the plantations studied, the fact that labour requirements to protect them and ensure their productive output are fairly modest, and that labour costs in tropical Africa are in any case low. It is possible that operating costs have been underestimated in several cases, a factor which will have overvalued profitability.

Estimates for investment costs, largely based on concrete examples, are more widely dispersed. In general terms the costs of establishing a plantation stand at between US $ 200 and 500/ha excluding enclosures, with some exceptionally high values (*Acacia cyanophylla*, US $ 600) and others which are very low (*A. albida*, US $ 55; *Leucaena*, US $ 150). Unit costs nevertheless appear less widely dispersed, usually varying around US $ 0.50 per plant, with some values appreciably lower (US $ 0.20-0.25) when the planting density is high, as for *Atriplex*, or when planting is carried out by direct drilling and not by transplanting young plants raised in the nursery (*Leucaena* and *Prosopis tamarugo*). Direct drilling, which is very much less expensive, cannot be used for the time being in the semi-arid and arid zones of tropical Africa, where it is too risky. In areas where rainfall is unreliable even transplanting nursery plants is not without risk, and so requires special care (the plants must be watered) to ensure survival. As a result tree and bush plantations in these areas are fairly expensive. A second factor further increases plantation establishment costs, namely the high cost price of barbed wire fencing. An alternative solution, far less expensive south of the Sahara, consists of planting thorn hedges. However, this solution has the drawback of prolonging the non-productive pre-development period. In short, it may be estimated that in tropical Africa a forage tree or bush plantation with a density of 1000 stocks/ha costs on average US $ 500/ha without expenditure on enclosures, and that estab-

A related problem arises in the form of non-utilization of the grass stratum, the value of which has been estimated on the basis of the same shadow prices as those used to assess browse production. As has been seen, this assumption was based mainly on the idea that grass is becoming scarce in tropical Africa, so that browse should not be produced to the detriment of grass but rather as a complement to it, enabling livestock to be supplied with forage throughout the year at reasonably low cost. Estimating cost prices on the basis of the more easily determined opportunity cost of capital thus not only obviated the need to rely on shadow prices which were more or less meaningless, but also provided a range of prices, which turned out to be a more useful approach. Uncertainties regarding investment costs and the level of forage yields have also been used to analyse the sensitivity of browse cost prices, with the different figures being considered as variables enabling profitability thresholds to be determined.

The IRR thus appears extremely sensitive to variations in investment costs and forage yields, especially when these are low. This emerges clearly from Table 21, which reproduces variations in average IRR for different plantations as a function of investment and yield variations. According to these results the IRR falls

Table 21.

IMPACT OF INVESTMENT EXPENDITURES AND YIELDS ON IRR OF BROWSE TREE AND BUSH PLANTATIONS[a].

- in % -

	Investment		Production		
	No enclosure (US $ 365)[b]	Barbed wire (US $ 815)[b]	500 FU	1000 FU	2000 FU
Atriplex	25.8	16.1	9.5	18.6	28.9
Acacia cyanophylla	16.2	12.3	4.0	12.4	19.6
Phyllodineous acacia	22.5	12.1	10.6	22.9	-
Acacia senegal	11.8	4.7			
Acacia albida	19.3	8.2			
Prosopis	20.9	9.6			
Total[c]	19.4	10.5	8.0	17.9	23.2

a. Project life of 20 years (30 years for *Acacia albida*); shadow prices of US $ 0.16/FU and US $ 0.24/kg of DP.

b. Average investment per hectare.

c. Average IRR.

by almost 0.5% when investment costs rise by 1%. IRR variations in relation to browse yields are even stronger when these are low, with IRR doubling when browse production moves from 500 to 1000 FU/ha, and increasing by almost 50% when production rises from 1000 to 2000 FU/ha (Table 21). If a level of 10 or even 15% is identified as the minimum IRR, it appears that on the basis of the FU and DP shadow prices adopted the profitability of browse plantations is assured at all production levels when investment costs do not include enclosures, and that this threshold generally seems to rise to 1000 FU when investments include barbed wire fences. Using hedges instead helps to improve IRR slightly, but even with them it usually remains below 10% (Table 22).

The production of wood or other products at the same time as browse (for example the improvement in crop yields produced by *Acacia albida*) nevertheless appears in several cases to lower the FU and DP cost prices significantly, resulting in the improved financial viability of browse production. Nonetheless, even when wood is produced at the same time, the production levels generally anticipated for tropical Africa only appear likely to allow browse production at sufficiently low prices (under US $ 0.10/FU) when no enclosures at all are used (Table 23).

A further factor which has not so far been quantified is that planting trees and bushes in particularly arid zones is rather a risky undertaking. Risks can be indirectly taken into account by raising the opportunity cost of capital adopted for estimating the FU and DP cost prices. A comparison between the cost prices when IRR is 15% instead of 10%, is interesting in this respect (Table 23). Except in a very few cases, with IRR at 15% browse cannot be produced at sufficiently low cost (under US $ 0.10/FU) when yields are lower or equal to 500 FU. When yields are 1000 FU/year, FU cost prices are only lower than US $ 0.10 when conditions are at their most favourable, with no enclosure costs, simultaneous production of wood, and use of the grass stratum at the same time as production of browse. When the opportunity cost of capital is 15%, yields have to approach 1500 FU/ha before browse can be produced at prices which are low enough (under US $ 0.10), or even 2000 FU when the grass stratum, evaluated similarly to browse, cannot be used at the same time as the latter (*Acacia cyanophylla*).

To sum up, the economic viability of browse tree and bush plantations appears uncertain from many aspects, when all the factors liable to limit profitability under current African conditions are taken into account. Given environmental constraints, initial efforts to improve this situation should probably involve lowering the investment cost of enclosures and maintaining the option to use the grass stratum during the development period, so that investment expenditure is kept at sufficiently low level not only to enable maximum growth of net forage output, but also to provide a high-quality supply during periods when livestock are severely underfed. Seen from this angle, browse tree and bush plantations would appear

Table 22.

IMPACT OF BROWSE YIELD ON IRR OF BROWSE TREE AND BUSH PLANTATIONS[a]

- in % -

	Browse production (FU)				
	<500	500	1000	1500	2000
Atriplex		6/8/14	15/16/25	20/29/31	23/24/34
Acacia cyanophylla[b]		0/0/4	8/9/14	13/14/19	16/17/23
Phyllodineous acacia		7/9/16	17/19/29		
Acacia senegal (Senegal)	4/6/11				
Acacia senegal (Sudan)	5/7/13				
Acacia albida	8/11/19				
Prosopis	10/12/21				

a. For each level, estimated IRR concern plantations with barbed wire fences/hedges/no enclosure under the following assumptions: project life of 20 years (30 years for *Acacia albida*); shadow prices of US $ 0.16/FU, US $ 0.24/kg of DP, US $ 7.8/t of *Atriplex* wood and US $ 15.6/t of other wood.

b. Production lost throughout the project period owing to non-utilization of the grass stratum is evaluated using the same shadow prices as for browse.

Table 23

FU AND DP COST PRICES ON BROWSE TREE AND BUSH PLANTATIONS[a]

- in US cents/FU -

IRR	IRR of 10%					IRR of 15%				
Production (FU)	< 500	500	1000	1500	2000	< 500	500	1000	1500	2000
Barbed wire fences										
Atriplex		b/b	12/10	9/7	7/5		b/b	b/16	13/11	10/8
Acacia cyanophylla		b/b	b/15	13/9	10/5		b/b	b/b	b/16	b/12
Phyllodineous acacia		b/b	14/				b/b	b/13		
Acacia senegal	/b					/b				
Acacia albida	b/b					b/b				
Prosopis	b/b					b/b				
Hedges										
Atriplex		b/b	11/9	8/6	6/5		b/b	16/14	11/9	9/7
Acacia cyanophylla[c]		b/b	b/13	12/8	9/5		b/b	b/b	b/b	b/14
Phyllodineous acacia		b/b	12/8				b/b	b/12		
Acacia senegal	/b					/b				
Acacia albida	b/14					b/b				
Prosopis	b/16					b/b				
No enclosure										
Atriplex		13/11	7/6	5/4	5/3		b/b	10/8	7/5	6/4
Acacia cyanophylla		b/b	13/9	9/[illegible]	7/4		b/b	b/16	14/9	11/7
Phyllodineous acacia		15/10	9/4				b/15	11/7		
Acacia senegal	/b					/b				
Acacia albida	6/3					15/10				
Prosopis	9/7					18/9				

a. Without wood production/with wood production.
DP cost price is assumed to be 1.5 times higher than FU cost price; project life is 20 years (30 years for *Acacia albida*)

b. Cost prices are higher than shadow prices

c. Production lost throughout the project period owing to non-utilization of the grass stratum is evaluated using the same shadow prices as for browse.

to provide some solution, and probably a more efficient one than the unreliable supply of feed concentrates, to the problems of livestock feed supplies in Africa. Their value is beyond question if their advantages in terms of energy supplies (wood) and environmental protection are also taken into account. Efforts should therefore be made to gain a better understanding of the very real opportunities offered by various species, and of the conditions under which they can grow and be used to help satisfy the vast browse and energy requirements of the arid and semi-arid zones of tropical Africa.

However optimistic, such a prospect nevertheless leaves unsolved the problem of effectively implementing plantations and distributing their produce to the pastoral population. Considering the probable costs involved, distribution would under any circumstances have to rely on a fair price for the services rendered.

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PARTICIPANTS AND CONTRIBUTORS

PARTICIPANTS

1. **Dr. B. Bensalem**
Forest. Res. Div. FAO
Rome 00100, Italy

2. **M. R. Bouchamaoui**
BP 1500 RP,
Tunis, Tunisia

3. **Mr. P.N. De Leeuw**
CIPEA BP 60
Bamako, Mali

4. **Prof. N. Dyson-Hudson**
ILCA, P.O. Box 46847,
Nairobi, Kenya

5. **Dr. M. Griffiths**
Ministry of Agriculture
Nairobi, Kenya

6. **Mr. T. Ionesco**
FAO/AGP
Via delle Terme di Caracalla
Rome, 00100 Italy

7. **Mr. P. Mosenyane**
c/o ILCA, P.O.Box 455
Gaborone, Botswana

8. **Mr. P. Monteiro**
Project UNDP/FAO/CVI/002
Praia, Cape Verde

9. **Mr. E. Pabot**
D-8580 Bayreuth
Postfach 3008
Universitatsstrasse Be 30

10. **Mr. G. Poulsen**
IDRC, P.O. Box 30677
Nairobi, Kenya

11. **Mr. D.J. Pratt**
ILCA, P.O. Box 5689
Addis Ababa, Ethiopia

12. **M.R. Sandford**
IMB, P.O. Box 1052
Addis Ababa, Ethiopia

13. **Dr. A.G. Seif el Din**
IDRC, P.O. Box 30677
Nairobi, Kenya

14. **Dr. M. Skouri**
UNESCO
Avenue Roume
P.O. Box 3311
Dakar, Senegal

15. **Mr. F. Torres**
ICRAF, P.O. Box 30677
Nairobi, Kenya

PARTICIPANTS AND CONTRIBUTORS

16. **M.J. Audru**
IEMVT, 10 rue P. Curie,
94700 Maisons Alfort, France

17. **Mr. C.I.A. Beale**
UNDP/FAO P.O. Box 553
Banjul, Gambia

18. **Dr. J.C. Bille**
ILCA, P.O. Box 46847
Nairobi, Kenya

19. **Mr. G.G. Boudet**
IEMVT, 10 rue P. Curie,
94700 Maisons Alfort, France

20. **Dr. B.A.R. Carew**
ILCA, P.O. Box 5320
Ibadan, Nigeria

21. **Dr. M.I. Cisse**
CIPEA, BP 60
Bamako, Mali

22. **Mr. M. Corra**
ILCA, P.O. Box 5689
Addis Ababa, Ethiopia

23. **Dr. A.K. Diallo**
Laboratoire d'Elevage
BP 2057, Dakar, Senegal

24. **Dr. (Mrs) M.S. Dicko-Touré**
CIPEA, BP 60
Bamako, Mali

25. **Dr. P. Felker**
Dept. of Soil and
Environmental Sces,
University of California,
Riverside 92521
California, U.S.A.

26. **Dr. H. Gillet**
Laboratoire d'Ethnobotanique
57 rue Cuvier,
75005 Paris, France

27. **Mr. P. Gosseye**
CIPEA, BP 60
Bamako, Mali

28. **Dr. Grouzis**
ORSTOM, Biologie Vegetale
BP 182, Ouagadougou
Haute-Volta

29. **Dr. H. Hadri**
BP 1500, 1055 Tunis R.P.,
Tunisie

30. **Mr. O. Hamel**
Centre Nat. Rech. Forest.
BP 2312 Dakar-Hann
Senegal

31. **Dr. G.N. Harrington**
Div. of Land Resources Management
CSIRO Riverina Laboratory,
Private Bag. P.O. Deniliquin
NSW Australia 2710

32. **Dr. P. Hiernaux**
CIPEA, BP 60
Bamako, Mali

33. **Dr. H. Lamprey**
UNED P.O. Box 30552
Nairobi, Kenya

34. **Dr. R.M. Lawton**
ODM Div. of Land Resources,
Tolworth Tower, Surbiton,
Surrey, KT6 DY England

35. **Dr. H.N. Le Houérou**
ILCA, P.O. Box 5689
Addis Ababa, Ethiopia

36. **Miss M.C. Lepape**
UNDP/FAO/CVI/002
Praia, Cape Verde

37. **Prof. C.M. McKell**
Dept. of Range Science, Utah State,
University Logan,
Utah 84321, U.S.A.

38. **Dr. I. Mecha**
Dept. of Animal Science,
University of Nigeria
Nsukka, Nigeria

39. **Mr. A. Nyerges**
Anthropology Dept. 325,
University Museum
University of Pennsylvania
Philadelphia, Pennsylvania, 19104
U.S.A.

40. **Dr. V.A. Papanastasis**
Forest Res. Institute Vassilika
Thessaloniki, Greece

41. **Dr. R.A. Pellew**
Kennete Graik Laboratory
Dept. of Physiology
Downing Street
University of Cambridge
CB2 3EG Cambridge, England

42. **Mr. J. Piot**
CIFT, BP 303
Ouagadougou, Haute-Volta

43. **Mr. A.G. Robertson**
Livestock and Meat Board
P.O. Box 1052,
Addis Ababa, Ethiopia

44. **Dr. R. Savory**
UNDP/FAO
P.O. Box 54
Gaborone, Botswana

45. **Mr. M.S. Taylor**
UNDP/FAO/ET/74/002
P.O. Box 5580,
Addis Ababa, Ethiopia

46. **Mr. B. Toutain**
IEMVT, 10 rue P. Curie
94700 Maisons Alfort, France

47. **Prof. B.H. Walker**
Dept. of Botany and Microbiology
University of the Witwatersrand
Jan Smuts Avenue
Johannesburg, 2001, South Africa

CONTRIBUTORS

48. **Dr. T.A. Adegbola**
Dept. of Animal Science
University of Nigeria
Nsukka, Nigeria

49. **Dr. R.W. Benjamin**
Gilat Regional Experiment Station
Mobile Post, Negev, Israel

50. **Dr. R.H. Braun Wilke**
Argentine Institute for Research
on Arid Lands (IADIZA)
c.c. 507, Mendoza (5500),
Argentina

51. **Mr. J.A. Breen**
FAO, Lilongwe, Malawi

52. **Mr. G.H. Cannell**
Dept. of Soil and
Environmental Sciences
University of California
Riverside 92521
California, U.S.A.

53. **Dr. J.C. Clanet**
Dept. de Géographie
Université de N'Djamena
Chad

54. **Mr. P.R. Clark**
c/o ILCA, BP 5320
Ibadan, Nigeria

55. **Mr. G.C. De Kock**
Grootfontein College of Agriculture
Middleburg, Cape Province 5900
South Africa

56. **Mrs. Cl. de Montgolfier-Kouévi**
ILCA Headquarters
Addis Ababa, Ethiopia

57. **Mr. D. Dumancic**
FAO, Casier Postal ONU,
Rabat Chellah, Maroc

58. **Mr. G.N. Egbuike**
c/o ILCA, P.O. Box 5320
Ibadan, Nigeria

59. **Dr. Ch. Field**
UNESCO/IPAL, P.O. Box 30592
Nairobi, Kenya

60. **Dr. Ch. Floret**
CEPE, BP 5051
34033 Montpellier Cedex
France

61. **Dr. D. Herlocker**
UNESCO/IPAL, P.O. Box 30592
Nairobi, Kenya

62. **Dr. E. Le Floch**
CEPE, BP 5051
34033 Montpellier Cedex
France

63. **Prof. L.G. Liacos**
School of Agriculture and Forestry
University of Thessaloniki
Thessaloniki, Greece

64. **Mr. C.V. Malcolm**
W.A. Dept. of Agriculture
Jarrah Road, South Perth
W. Australia 6151

65. **Dr. H.S. Mann**
Director General
Central Arid Zone Research Institute
Jodhpur, India

66. **Mr. A.U. Mba**
c/o ILCA, P.O. Box 5320
Ibadan, Nigeria

67. **Dr. G.K. Mosi**
ILCA Headquarters
Addis Ababa, Ethiopia

68. **Mr. J. Osborn**
Dept. of Soil and
Environmental Sces
University of California
Riverside 92521
California, U.S.A.

69. **Dr. K.A. Shankarnarayan**
CAZRI, Jodhpur, India

70. **Dr. M. Sicot**
ORSTOM, BP 182, Ouagadougou,
Haute-Volta

71. **Mr. T.C. Swaan**
W.A. Dept. of Agriculture
Jarrah Road, South Perth
W. Australia 6151

72. **Dr. J. Valenza**
Laboratoire Central d'Elevage
BP 2057, Dakar-Hann,
Sénégal

73. **Dr. G.E. Wickens**
Royal Botanic Gardens,
Kew, Richmond, Surrey
TW9 SAB, England

74. **Dr. A.D. Wilson**
CSIRO, Division of Land Resources
Management, Riverina Laboratory,
Private Bag. Deniliquin
NSW, Australia 2710

75. **Mr. R.T. Wilson**
CIPEA, BP 60
Bamako, Mali

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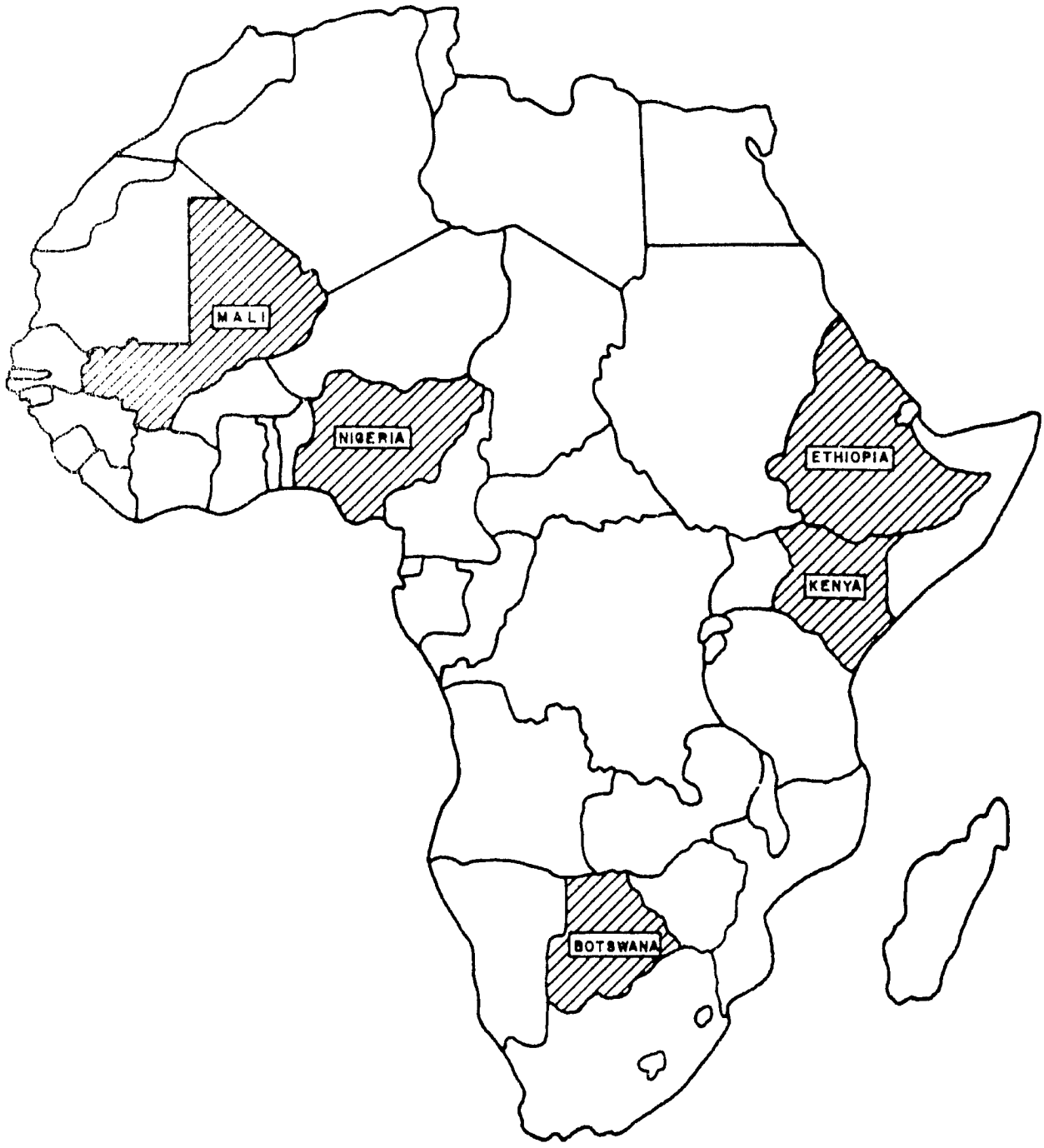

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