

THE ROLE OF FORESTRY IN FARMING  
SYSTEMS WITH PARTICULAR REFERENCE  
TO FOREST-GRAZING INTERACTIONS

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## APPENDIX I

Definition of Country Groups.

The country groups used in Chapter 1 were defined by CAS (1980) as:

Low Income (Developing Countries) with income per person (1976 GNP per head per year) of US \$250 or less. These countries were divided into Low Income Africa and Low Income Asia (including others);

Middle Income (Developing Countries) with income per person above US \$250;

CSOE: Capital Surplus Oil Exporters with GNP per person per year of \$4480 to \$15480;

Low CPE: Low Income Centrally Planned Economies with GNP per head per year below \$1000;

High CPE: High Income Centrally Planned Economies with GNP per head per year ranging from \$2280 to \$4220;

Industrialised Countries with GNP per head in 1976 ranging from \$2590 to \$8880.

## APPENDIX 2

Conversion Factors, Abbreviations and Symbols

ACU:	Adult Cattle Unit
ADM:	air dry matter
Ca:	calcium
cal:	calorie
CP:	crude protein
CPD:	crude protein digestibility
CPRL:	common property rangeland
dbh/DBH:	diameter breast height (1.30 cm)
DCP:	digestible crude protein
DM:	dry matter (assumed oven dry)
?DM:	dry matter (unknown how dried)
DMD:	dry matter digestibility
DMI:	dry matter intake
DW:	dry weight (assumed oven dry)
E:	Einstein (energy of a mole)
EPT:	evapotranspiration
erg:	measure of energy; 1 erg = $2.389 \times 10^{-8}$ cal.
FW:	fresh weight
GDP:	gross domestic product
J:	Joule, measure of heat energy 1J= 0.2388 cal.
K:	measure of temperature 1K = 1°C
klux:	measure of illumination; 1 klux = $0.017 \text{ cal cm}^{-2} \text{ min}^{-1}$
$\lambda$ :	wavelength

LAI: leaf area index

LAR: leaf area ratio

Mg: magnesium

Na: sodium

nm: nanometer (wavelength measure)

P: refers to phosphorus or precipitation depending on the context

p.a.: per annum

PAR: photosynthetically active radiation

Pfr: P 730 = phytochrome far red

Pr: P 660 = phytochrome red

s: second

SLA: specific leaf area

sph: stems per hectare

?W: plant weight; degree of dryness unknown

$W^{0.75}$ : metabolic live weight (animals)

W: Watts; measure of heat flux  $1 \text{ W m}^{-2} = 2.388 \times 10^{-5} \text{ cal cm}^{-2} \text{ s}^{-1}$

WP: Woody perennial

## APPENDIX 3

Acronyms

- APROSC: Agricultural Projects Services Centre (Kathmandu, Nepal).
- BAT: British American Tobacco (Nairobi, Kenya).
- CAB: Commonwealth Agricultural Bureau (Farnham, UK).
- CAS: Centre for Agricultural Strategy (Reading, UK).
- CATIE: Centro Agronomico Tropical de Investigacion y Ensenanza,  
Turrialba (Costa Rica).
- CAZRI: Central ARid Zone Research Institute (Jodhpur, India).
- CSIRO: Commonwealth Scientific and Industrial Research Organization  
(Australia).
- CSWCRTI: Central Soil and Water Conservation Research and Training  
Institute (Dehra Dun, India).
- CTFT: Centre Technique Forestier Tropical (Nogent sur Marne,  
France).
- ESCA: East of Scotland College of Agriculture (Edinburgh, UK).
- FAO: Food and Agriculture Organization (Rome, Italy).
- HFRO: Hill Farming Research Organization (Midlothian, UK).
- IAB: Imperial Agricultural Bureau (now CAB see above).
- IBRD: International Bank for Reconstruction and Development  
(Washington D.C., USA).
- ICAR: Indian Council for Agricultural Research (New Delhi, India).
- ICRAF: International Council for Research in Agroforestry (Nairobi,  
Kenya).
- ICRISAT: International Crops Research Institute for the Semi-Arid  
Tropics (Andhra Pradesh, India).
- IGFRI: Indian Grassland and Fodder Research Institute (Jhansi,  
India).

IICA: Instituto Interamericano de Ciencias Agricolas (Costa Rica).  
ILCA: International Livestock Centre for Africa (Addis Ababa, Ethiopia).  
IPAL: Integrated Project in Arid Lands (Nairobi, Kenya).  
ITE: Institute of Terrestrial Ecology (Huntingdon, UK).  
IUFRO: International Union of Forest Research Organizations.  
IVRI: Indian Veterinary Research Institute (Palampur, India).  
LRDC: Land Resources Development Centre (Surrey, UK).  
ODI: Overseas Development Institute (London, UK).  
UN: United Nations (New York, USA; Nairobi, Kenya).  
UNEP: United Nations Environmental Programme (Nairobi, Kenya).  
UNESCO: United Nations Educational and Scientific and Cultural Organization (Paris, France).  
USDA: United States Department of Agriculture.



## APPENDIX 4

The area of W Rajasthan (see Fig. A.4.1).

While W Rajasthan includes 12 districts (Barmer, Bikaner, Churu, Ganganagar, Jaisalmer, Jalore, Jhunjhunu, Jodhpur, Nagaur, Pali, Sikar and Sirohi), a major discrepancy has been found in that the various authors from CAZRI and elsewhere who refer to W Rajasthan (or often interchangeably with arid Rajasthan) may include the 12 districts or only eleven and may then omit any one of Jhunjhunu (e.g. Jodha 1977) or Sirohi (e.g. Gupta 1971); they usually do not state which districts they include when referring to W Rajasthan.

The total area of the 12 districts amounts to 213 994 km<sup>2</sup> (derived from Kapoor 1984). The total area used here is 208 220 km<sup>2</sup> (as in Appendix 6) and originates from Mann et al (1977a). It is further assumed that where the latter authors referred to "acres" for the area of the region, they meant "hectares"; this then corresponds with their omission of the district of Jhunjhunu which has an area of 5913 km<sup>2</sup> (Kapoor 1984). The reason for choosing an area which omits Jhunjhunu in this analysis is that the livestock figures used in Appendix 7a also originate from Mann et al (1977a) and are therefore assumed to exclude livestock numbers from that district.

The areas of the districts of Sirohi and Ganganagar cover 5127 km<sup>2</sup> and 20696 km<sup>2</sup> respectively. Hence the possible margin of error in this analysis, due to including data from 12 districts or omitting data from one district could range from + 5127 to + 20696 km<sup>2</sup> in relation to a surface area of 208220 or 213994 km<sup>2</sup>, i.e. - 2.4% to -9.7% or + 2.4% to + 9.9%.

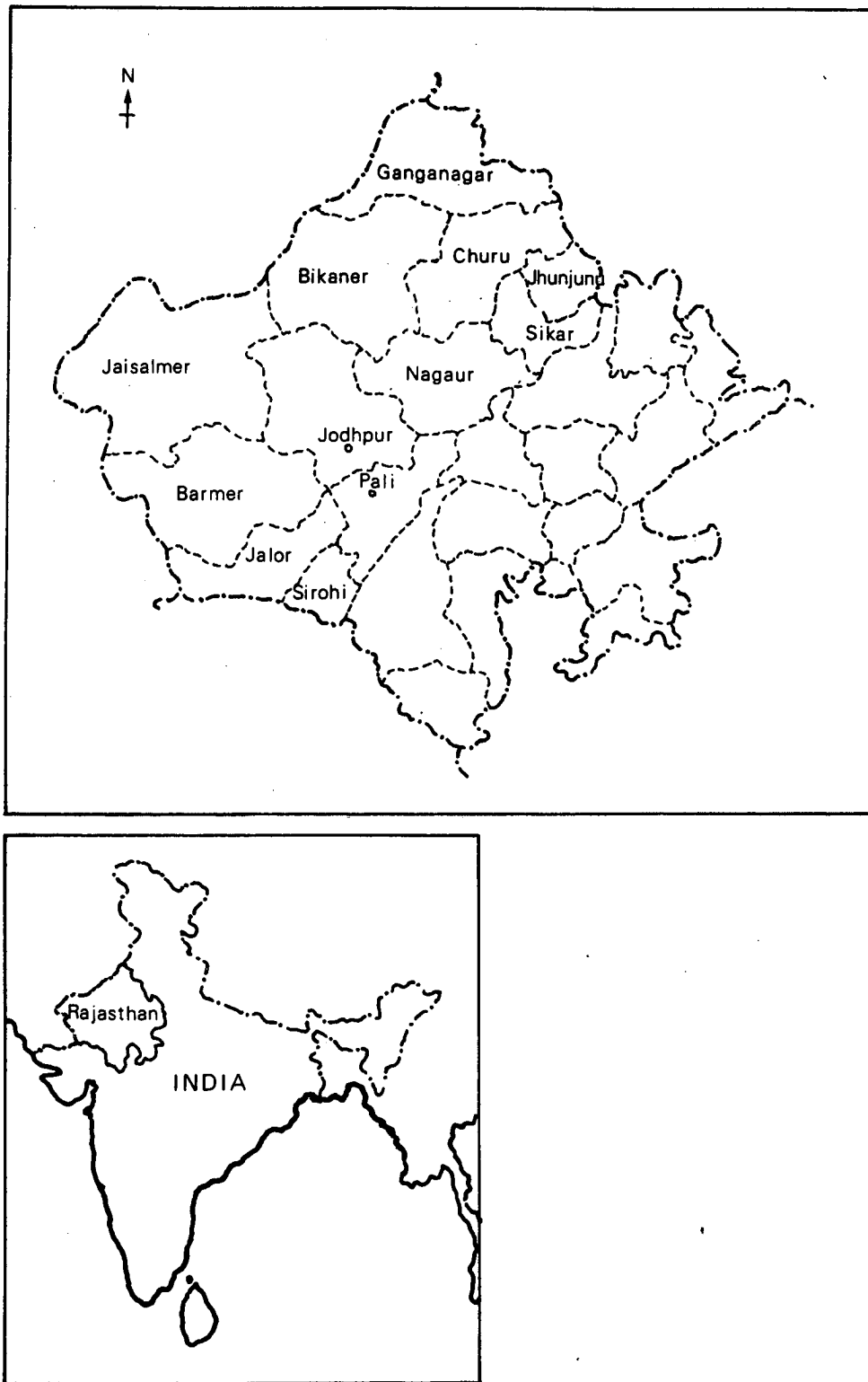


Fig. A.4.1. Location of Rajasthan showing districts of W. Rajasthan.

## APPENDIX 5

A. Nutrient status of some soils<sup>1/</sup> in W Rajasthan  
(derived from Dhir 1977)

Status	Available Phosphorus (Kg/ha)	Organic C (% dw)
Low	< 9.9 (22%) <sup>2/</sup>	< 0.5 (82%)
Medium	9.9-24.6 (42%)	0.5-0.75 (10%)
High	> 56 (35%)	> 0.75 (8%)

Notes: 1/ These figures are not representative of all the soils of W Rajasthan. They are derived from soils tested as part of the farmers' advisory programme and therefore presumably refer to cropland soils.

2/ The percentages in brackets indicate the percentage number of soil samples which showed the corresponding values.

B. Nitrogen status of some soils of W Rajasthan.

It has been assumed that because the organic C levels are generally low, the total available N levels must also be low (Dhir 1977 p.110). However C/N ratios have been found to vary from 4 to 13 depending on the site and depth of sampling in a higher rainfall zone of the area, suggesting reasonable rates of N mineralization (Thomson et al 1973). Raychandhuri (1978) also suggested that the levels of available N for T Rajasthan are low and for the desert areas gave values for total N ranging from 0.02 to 0.07% (dm).

## APPENDIX 6

Land use pattern of the arid districts of  
W Rajasthan in 1961 and 1971 (000 ha)  
 (derived from Mann et al 1977a)

	<u>1961</u>	<u>1971</u>
<u>Total area</u>	20822	20862
<u>I Land not available for cultivation</u>		
a) forest	163	168
b) non agric. uses	591	662
c) barren	2383	2349
d) total	3137	3179
<u>II Other uncultivated land.</u>		
a) permanent pasture	707	773
b) misc. tree crops	1	2
c) cultivable waste	4710	4561
d) total	5418	5336
<u>III Fallow land</u>		
a) not current fallow	2478	1911
b) current fallow	1580	1191
c) total	4058	3102
<u>IV Cultivated land</u>		
a) net area sown	8209	9247
b) total cropped area	8325	9577
c) area sown more than once.	116	330

## APPENDIX 7A

## Livestock population and livestock units in W. Rajasthan in 1961 and 1972

Livestock type	1961					1972				
	1/ Livestock Nos	2/ AU	3/ CU	4/ ACU/TCU	5/ ACU/TCU <sup>0.75</sup>	1/ Livestock Nos	2/ AU	3/ CU	4/ ACU/TCU	5/ ACU/TCU <sup>0.75</sup>
Cattle	44 104 70	44 104 70	44 104 70	3307853	A Y 2205235 1301089	3480752	3480752	3480752	26 105 64	A Y 1740376 1026822
Buffalo	967304	967304	967304	725478	A Y 483652 285355	1108764	1108764	1108764	83 15 73	A Y 554382 327085
Sheep	4354835	653225	1088709	435484	A Y 580645 174 193	5159784	773968	1289946	5 159 78	A Y 687971 206391
Goat	3429127	5 14 369	857282	342913	A Y 457217 137165	5814 174	872126	1453544	58 14 17	A Y 775223 232567
Horse	18496	18496	9248	13872	A Y 13409 1603	10058	10058	5029	7544	A Y 7292 872
Mule	285	285	143	242		175	175	86	149	
Donkey	91962	45981	45981	32187	A Y 36555 7357	78878	39439	39439	27607	A Y 31354 6310
Camel	621340	621340	2485360	714541	A Y 526068 155335	623926	623926	2495704	720965	A Y 528258 155981
Pig	5334	2667	2667	600		9553	4777	4777	2866	A 4203
Total	13899153	7234137	9867164	5574170	6367473	16286064	6913985	9878041	5298663	6285239

Notes: 1/ from Mann *et al.* (1977a).

2/ AU = "Animal Unit" from Jodha (1980): "1 cattle/camel = 1 AU; 1 sheep/goat = 0.15 AU". Further assumptions: 1 horse/buffalo/mule = 1 AU; 1 donkey/pig = 0.5 AU.

3/ CU = "Cattle Unit" from Gupta (1971): "1 cow/bull = 1 CU; 1 mule/horse = 0.5 CU; 1 sheep/goat = 0.25 CU; 1 camel = 4 CU". Further assumptions: 1 buffalo = 1 CU; 1 donkey/pig = 0.5 CU.

4/ ACU/TCU = "Adult Cattle Unit" or "Tropical Cattle Unit" from Ahuja (1977), Ahuja *et al.* (1975) and Das *et al.* (1980): "300 kg = 1 ACU/TCU". Assumptions (A:Y = Adult: Young ratio): cattle/buffalo A:Y = 1:1, A = 300 kg, Y = 150 kg (derived from Crotty 1980,

NAS 1981, Verma *et al.* 1979); sheep/goat A:Y = 1:0.5, A = 35 kg, Y = 18 kg (derived from Gosh *et al.* 1980, Patnayak 1980, Sen *et al.* 1981).

horses A:Y = 1:0.2, A = 250 kg, Y = 125 kg; donkey A:Y = 1:0.33, A = 130 kg, Y = 65 kg; camels A:Y = 1:0.5, A = 410 kg, Y = 205 kg (derived from IPAL 1982, Le Houerou *et al.* 1977, Macfarlane 1980, Wilson, 1982a). mules = 250 kg; pigs = 100 kg.

5/ ACU/TCU<sup>0.75</sup> = A:Y as in 4/ and liveweight converted to metabolic weight (W<sup>0.75</sup>) to take into account the non linear relationship between liveweight: DM intake.

Cattle and buffalo A/Y = x1.00/0.59; sheep and goat A/Y = x 0.20/0.12; horse A/Y = x0.87/0.52; mules = x0.87; donkeys A/Y = x0.53/0.32; camels A/Y = 1.27/0.75; pigs = x 0.44.

APPENDIX 7B

Livestock population and livestock units in W Rajasthan, 1951.

	<u>1/ Livestock Nos (A)</u>	<u>2/ Livestock Nos (B)</u>	<u>ACU/TCU</u>		<u>ACU/TCU<sup>0.75</sup></u>
Cattle	3431000	3264940	2448705	A Y	1632470 963157
Buffalo	775000	727802	545852	A Y	363901 214702
Sheep	3374000	3264345	326435	A Y	435246 130574
Goat	2370000	2219979	221998	A Y	295997 88799
Camel	214000	214000	246100	A Y	181187 53500
Others <sup>3/</sup>	104000	104000	41600	A Y	46020 10140
Total	10268000	9795066	3830690		4415693

Notes: 1/ from Mann et al (1977c) - assumed to include 12 districts.

2/ Livestock numbers corrected to exclude estimated numbers of livestock from Jhunjhunu district in 1951; correction factor calculated by assuming that the percentage difference in numbers between the 12 districts (Mann et al 1977c) and the districts excluding Jhunjhunu (Mann et al 1977a) in 1961 is the same as in 1951. Correction factors: cattle - 4.84%; buffalo - 6.09%; sheep - 3.25%; goat - 6.33%; camel and others no difference.

3/ Assumptions: 17% horses, 83% donkeys and otherwise same assumptions as in Appendix 7A.

APPENDIX 8

Area under various crops in W Rajasthan in 1970 (Mann et al. 1977c) and 1977-1978 (CAZRI 1983)  
(figures in brackets indicate estimates - see notes).

	1/ 1970 Area (000 ha)	2/ 1977-1978 Area (000 ha)	3/ 1970 - derived area (000 ha)			
			Unirrigated		Irrigated	
			Area	% area	Area	% area
<u>Pennisetum typhoides</u>	3450	3380	3450	36.8		
<u>Sorghum vulgare</u>	150		150	1.6		
<u>Cyamopsis tetragonoloba</u>		2682	(3719)	39.7		
<u>Vigna aconitifolia</u>	] 1500	1410	(1311)	14.0		
<u>Vigna radiata</u>						
<u>Cicer agrietinum</u>			( 226)	2.4	(224)	32.3
<u>Sesamum indicum</u>	220	290	220	2.3		
<u>Triticum aestivum</u>	355				355	51.2
<u>Hordeum vulgare</u>	95				95	13.7
<u>Oryza sativa</u>					( 20)	2.9
Other crops		86	( 100)	1.1		
Total	(10059)		(9365)	99.9	(694)	100.1

Notes:

1. The 1970 figures refer to the area under "the important crops grown in the arid zone of Rajasthan" (Mann' et al. 1977c). It is assumed these figures refer to the area covered by 12 districts since elsewhere in the paper this is stated to be the case.
2. The 1977-1978 figures refer to the important crops grown under "dry farming" conditions in W Rajasthan (CAZRI 1983) and are therefore assumed to exclude land under irrigation (various crops grown under irrigated conditions in the area are excluded from their list). It is assumed that the figures refer to an area covered by less than 12 districts since when added up with the area which is believed to be irrigated, they fall short of the total area estimated to have been sown in W Rajasthan in 1970 by 470 000 ha which is close to the sown area of Jhunjunu district (465 000 ha - derived from Jodha 1977). For the explanation of how the total area was derived see note 3, ii.
3. The 1970 "derived area" gives an estimate of the area under various irrigated and unirrigated crops for 1970 for 12 districts. The estimates of the proportions of the various crops within the irrigated and unirrigated categories are necessary to derive figures for crop residue production and feed quality from the 1971 figures which this analysis is based on. Although figures for areas under various crops in 1971 are available from some sources (eg. Jodha 1977), they do not obviously correspond in anyway with the total sown area with which this analysis is working and have therefore been disregarded. The assumptions used to arrive at these figures are as follows:
  - i. the total area under irrigation was derived from the assumption that the 330 000 ha assumed to be sown more than once (Appendix 6) in the area are all irrigated and that the net



area under irrigation in Jhunjunu district amounts to 17 200 ha (Jodha 1977) ( $(330 \times 2) + (17 \times 2) = 694$ ). The total net area under irrigation also corresponds broadly with Jodha's (1977) figures on net irrigated area as a percentage of net cultivated area for W Rajasthan (and on the understanding that Jodha excluded Ganganagar district which is known to have an above average proportion of land under irrigation);

ii. the total area sown for the 12 districts has been calculated on the basis of the total area sown given in Appendix 6, plus the net area sown in Jhunjunu (465 000 ha) and the area believed to be sown a second time in the year in Jhunjunu (17 000 ha) (see above);

iii. the total area of unirrigated land which was sown is therefore 9365 000 ha (and this also equals the net sown area on rainfed sites);

iv. the two Vigna crops are sown in the same proportion as in 1977-78;

v. there was an omission in the 1977-78 data concerning Sorghum. Most authors mention that the crop is grown under dry farming conditions;

vi. an allocation of 20 000 ha is given to rice cultivation (and other crops) on the basis of evidence given by Mann et al. (1977c) and Roy et al. (1980). The remaining area must therefore be sown to Cicer;

vii. 226 000 ha are therefore sown to Cicer on unirrigated lands;

viii. 100 000 ha are sown to other crops on unirrigated lands which leaves the rest to Cyanopsis.

It is acknowledged that the resulting area sown to Cyanopsis is considerably larger than that given by CAZRI (1983) for 11 districts in 1977-78. However this is believed to be the most plausible scenario which has been investigated. The assumptions above also reject the figures given by Mann et al. (1977c) concerning the area under irrigation. Their figures (827 000 ha) were ambiguous in terms of whether referring to net area irrigated or total area irrigated. Further even if referring to total area under irrigation they do not fit as well with the more detailed information provided by Jodha (1977) on irrigated areas and with the figures provided in Appendix 6.

## APPENDIX 9

Estimated crop residue production and quality in W Rajasthan for irrigated and unirrigated crops in 1971.

Crop	% of area cropped <sup>1/</sup>	Area cropped <sup>2/</sup> (000 ha)	"Normal" year		"Dry" year		Chemical Composition <sup>13/</sup>	
			Yield <sup>13/</sup> (tonnes ?DM/ha)	Production <sup>13/</sup> (M tonnes ?DM)	Yield <sup>13/</sup> (tonnes ?DM/ha)	Production <sup>13/</sup> (M tonnes ?DM)	CP	Phosphorus
<b>I Irrigated</b>								
<u>Cicer agrietinum</u> (gram)	32.3	213	2.5 <sup>3/</sup>	0.533	2.5	0.533	11.0 <sup>8/</sup>	0.20 <sup>8/</sup>
<u>Triticum aestivum</u> (wheat)	51.2	338	2.5 <sup>3/</sup>	0.845	2.5	0.845	3.2 <sup>9/</sup>	0.13 <sup>9/</sup>
<u>Hordeum vulgare</u> (barley)	13.7	90	2.5 <sup>3/</sup>	0.225	2.5	0.225	2.2 <sup>9/</sup>	0.07 <sup>9/</sup>
<u>Oryza sativa</u> (rice)	2.9	19	2.5 <sup>3/</sup>	0.048	2.5	0.048	3.6 <sup>9/</sup>	0.17 <sup>9/</sup>
Total	100.1	660		1.651		1.651		
<b>II Unirrigated</b>								
<u>Pennisetum typhoides</u> (pearl millet)	36.8	3281	0.30 <sup>4/</sup>	0.984	0.20 <sup>4/</sup>	0.656	3.2 <sup>9/</sup>	0.18 <sup>9/</sup>
<u>Sorghum vulgare</u> (Sorghum)	1.6	143	0.20 <sup>5/</sup>	0.029	0.10 <sup>5/</sup>	0.014	3.6 <sup>10/</sup>	0.23 <sup>10/</sup>
<u>Cyanopsis tetragonoloba</u> (cluster bean)	39.7	3540	0.45 <sup>6/</sup>	1.593	0.15 <sup>6/</sup>	0.531	10.0 <sup>11/</sup>	0.21 <sup>11/</sup>
<u>Vigna aconitifolia</u> (dew gram)	14.0	1248	0.40 <sup>4/</sup>	0.499	0.20 <sup>4/</sup>	0.250	11.3 <sup>12/</sup>	0.12 <sup>12/</sup>
<u>Vigna radiata</u> (green gram)	2.0	178	0.60 <sup>4/</sup>	0.107	0.20 <sup>4/</sup>	0.036	11.6 <sup>12/</sup>	0.18 <sup>12/</sup>
<u>Cicer agrietinum</u>	2.4	214	0.40 <sup>14/</sup>	0.086	0.20 <sup>14/</sup>	0.043	11.0	0.20
<u>Sesamum indicum</u>	2.3	205	0.30 <sup>7/</sup>	0.062	0.10 <sup>7/</sup>	0.021	-	-
Other crops	1.1	98	-	-	-	-	-	-
Total	99.9	8917		3.360		1.551	-	-

Notes: 1/ Derived from Appendix 8.

2/ Total area from Appendix 6.

3/ No values were found for the production of these in Rajasthan. Rice straw yields in Nepal have been estimated at 2.1 tonnes (?DM)/ha (Mohs 1981); Pandey et al (1984) quoted values of 3.7 tonnes (FW) for residues from a wheat production system in Uttar Pradesh (containing "straw/hay/greens").

4/ The data on yields originates from CAZRI (1983). It is unfortunately not clear if these yields referred to "research station" yields -i.e. yields a farmer can expect to obtain with fertilizer and other non-traditional inputs. The long term average yield was given as 0.10 tonnes (?DM)/ha. But it is possible that these figures are purely estimates based on a reduction in residue yield due to drought in the same proportion as that found for grain yields. The basis for such an assumption would not be sound. Depending on the particular characteristics of the "dry" year, considerable vegetative growth may occur even though grain yields are poor. The "dry" year yield of dew gram was said by CAZRI to be the same as for a normal rainfall year even though the grain yields decreased 4 lines. It is assumed that this is not correct and that the residue yields would only be half that of a normal year during a moderate drought year.

5/ This is an estimate based on the understanding that Sorghum is a more marginal crop in W Rajasthan than pearl millet (e.g. Jodha 1977).

6/ This is an estimate assuming residue yields to be one quarter lower than for green gram (derived from data (?W) in Mann et al. 1977b on fertilized and well watered crops).

7/ This estimate is based on the data (?W) provided by Mann et al. (1977b) from a fertilized and well watered crop and Jodha's (1977) statement that Sesamum is a marginal crop in W Rajasthan.

8/ Estimate based on a slightly lower figure than that provided by Sen et al. (1978) for a crop including stem, leaves and grain (and defined as "roughage").

9/ Based on Sen et al. (1978).

10/ Based on Devendra et al. (1982).

11/ Based on a 20% reduction from values for a cultivated fodder (Sen et al. 1978).

12/ Based on Ranjhan et al. (1981).

13/ For plant weight definitions and conversion factors see Appendix 11.

14/ No data were found of yields of Cicer on unirrigated sites. These are therefore assumptions which are in line with the figures for other legumes.

## APPENDIX 10

Crop residue yields from areas  
other than W Rajasthan

The following figures on yields of agricultural crop residues which are fed to livestock originate from different regions of the world. It is against an awareness of these figures and the climatic conditions under which the crops were grown that the figures provided in Appendix 9 and originating largely from CAZRI (1983) have been accepted for want of more thorough data. However in accepting these figures, the average figure of 1.25 tonnes (?W) of feed from agricultural residue produced on each hectare of cultivated area in the arid zone of India is discounted; this is the figure which Ahuja (1975) used in his calculations of feed production for W Rajasthan, without any reference as to how it was derived, and which has been used since by several authors. CAZRI (1983) stated that the average yields of crops in W Rajasthan are very low compared to those of India as a whole and even of T Rajasthan.

1. It has been estimated that India's total production of crop residues available as livestock feed is 231.05 M tonnes (?W) (Patil et al 1980). By dividing this figure by the total net area sown in India in 1970-1971, 141 M ha (Mann et al 1977c), the average yield of agricultural residue assumed to be available as animal fodder is 1.64 tonnes (?W) per ha.
2. In the intensively farmed region of the Kano Close Settled Zone of northern Nigeria, a subhumid area (average P = 860 mm p.a., Kowal et al 1978), the average annual production of all agricultural residues is estimated to be 1.4 tonnes (?DM) per ha — sorghum leaves, millet leaves groundnut haulms and cowpea haulms producing 1.6, 1.0, 1.5 and 1.6 tonnes (?DM) respectively (ILCA 1979).

3. Investigations near Zaria (Nigeria) (average P = 1100 mm p.a. 90% of which falls in 5 months, Oyedipe et al 1982) indicated that farmers' fields planted to sorghum, groundnut and cowpea would provide 40 grazing days per ha if all the residue production was utilised by livestock (de Leeuw et al 1972). This production level was calculated on the basis of 1 Standard Cow Unit (272 kg) having a daily dry matter (?DM) intake of 6.8 kg. Hence the production of residues amounted to 272 kg (?DM) per ha per year (40 x 6.8).

4. The amount of crop residues available to livestock was estimated for 3 climatic zones of Borno State (Nigeria) by Avee Enterprises (1981); for the Sahel, Sudan and N. Guinea zones (average P ranging from 500 mm to 1000 mm p.a.) the average available production levels were 250, 400 and 700 kg (?DM) respectively. These estimates allowed for loss to fire (fuel consumption?), building purposes and "non-availability due to intercropping". The main cereals grown in the area are millet and sorghum, which occur in approximately equal proportions throughout the State, with a slight predominance of millet in the more arid north.

A considerable number of references were screened to try to obtain data on yields of agricultural residues, particularly from the intercropping literature (eg. Hall 1984, Papendick et al. 1976, Wiley 1979 a,b,), but with only few results.

## APPENDIX 11

Plant weight conversion factors

The data provided in the case study, concerning the weight of plant material are derived from sources which often do not specify if they are referring to fresh, air dry or oven dry weights (see also Robinson 1984a, Annexe 2). Further a number of sources were found which used any one of these. The need for standardization has resulted in the following assumptions and conversion factors being adopted.

- i) The code "(?W)" following any data indicates that the original author did not specify which weight he was referring to, and that an oven dry weight has been assumed in this analysis. It is realized that a considerable amount of data may have in fact referred to air dry weights or to fresh weights resulting in a margin of error in the analysis ranging from about 10 to about 80%.
- ii) "(FW)" indicates that the authors stated the values referred to fresh weight. Appropriate conversion factors may be used to convert such data to oven dry weight (DM - see below).
- iii) "(?DM)" indicates that the author referred to dry matter without specifying whether "air dry" or "oven dry". Oven dry weight has again been assumed with the same proviso as mentioned in (i) above.
- iv) "(ADM)" indicates that the authors referred specifically to air dry weights and these have again been converted to oven dry weights using the appropriate conversion factors. For all leaf or stem (non ligneous) material, the conversion factor of 0.9 from air dry to oven dry has been assumed (Sen et al 1978) unless otherwise stated.

- v) "(DM)" indicates either that the original data were specifically referred to as "oven air dry" or that the data have been converted to oven dry weights by the appropriate conversion factor. Hence, in the case of an incorrect assumption being made between air and oven dry material the error will be of the order of 10% from the point of view of biomass or chemical composition.

The DW of wood has been assumed to be 15% lower than ADM wood.

## APPENDIX 12

Phenology and palatability rating of the better fodder WPs of the NW arid zone of India

Season	WINTER					SUMMER			MONSOON					
	Months	Oct	Nov	Dec	Jan	Feb	(SPRING) Mrch	Apr	May	June	July	Aug	Sept	
Species	Plant part	Palatability												
<u>Acacia nilotica</u> (L.) Willd. ex Del.	L/ F2/	G3/ ?5/	6/					*****8/*****			9/			
<u>Prosopis cineraria</u> (Linn.) Druce	L F	G G	-----					*****			-----			
<u>Salvadora oleoides</u> Decne.	L	G						?10/						
<u>Salvadora persica</u> Linn.	L	G						?						
<u>Zizyphus nummularia</u> Burm.f.	L	G	-----					7/			11/			
<u>Acacia senegal</u> Willd.	L F	M4/ ?5/	-----					?			+			
<u>Acacia tortilis</u> (Forsk)	L F	M ?5/	-----					?			+++++			
<u>Ailanthus excelsa</u> Roxb.	L	M	-----					*****			-----			
<u>Albizia lebbek</u> (Linn.) Benth.	L	M	-----					*****			-----			
<u>Anogeissus pendula</u> Edgew.	L	M	-----					-----			*****			
<u>Anogeissus rotundifolia</u>	L	M						?						
<u>Brasilettia mollis</u> (H.B.K) Britton & Killip	L	M	-----					?						
<u>Calligonum polygonoides</u>	L	M						?						
<u>Colophospermum mopane</u> (Kirk ex Benth) Kirk ex J. Léon	L	M	-----					?						
<u>Dalbergia sissoo</u> Roxb.	L	M	-----					*****			-----			
<u>Dichrostachys glomerata</u> (Forsk) Chiov	L	M						?						
<u>Zizyphus spinachristii</u> (L.) Willd.	L	M						?						

**Notes:** 1/ L = leaf; 2/ F = fruit/pod; 3/ G = good; 4/ M = moderate; 5/ "?" in the column on palatability indicates that the fruits are eaten by livestock but no formal palatability assessment has been made in India. However the pods of *A. nilotica*, *A. senegal* and *A. tortilis* are stated to be of good to moderate feed quality in Africa ( e.g. Cisse 1983, von Maydell 1983).  
6/ ----- indicates the period in which the trees are in leaf.  
7/ - - - - - indicates the time of leaf shedding. Interannual climatic variations influence timing explaining the long period over which leaf shed can occur.  
8/ \*\* indicates the period of leaf flush.  
9/ + + indicates the period of fruit maturity.  
10/ "?" concerning phenology indicates that no published information has been found concerning the species in India.  
11/ Although the leaves do not unfold until the first rains, the sprouting of coppiced stumps starts in February/March and continues until June.

**Sources:** (Ganguli et al 1964, Mann et al 1984, Muthana et al 1979, Saxena 1980, 1981a, Singh 1982 and Personal observation).



## APPENDIX 13

Fodder yield and biomass estimates of  
Prosopis cineraria

The evidence concerning the yield of Khejri (Prosopis cineraria) is very inconsistent. The following paraphrase various authors' statements and discuss some of their results.

1. A moderate sized mature tree yields about 45 kg of leaves (?DM) (Ganguli et al 1964).
2. A fully grown tree (40 to 60 years old) produces 20-30 kg of leaves (ADM) per plant in the 300 to 400 mm rainfall zone. A Khejri tree is expected to be ready for lopping in its 8th year of growth (Saxena 1981b). (How the age of trees was determined is unclear since Khejri trees do not have rings Mann et al 1983).
3. A moderately grown tree yields nearly 25-30 kg of leaves (?DM) per year and trees are ready to provide animal feed from the 10th year onwards (Bohra et al 1980).
4. A fully grown and unlopped tree (30-50 years old) with a well spread crown produces nearly 5 kg of pods (ADM) in the 350-500 mm rainfall zone in good rainfall years. Young trees (10-30 year age group) which are "not much" lopped give 2-3 kg per tree (Muthana 1980).
5. The data obtained on foliar biomass by Mann et al (1983) using destructive sampling techniques (Fig. 8.2) refer to averages from five trees in each dbh class. The site was a flat alluvial plain but no information was given concerning the average rainfall for the site. Individual tree data were not mentioned and since no standard errors of the mean were provided, it is difficult to comment on the extent to which a drop in foliar biomass actually occurred at the higher dbh class. Several factors might have resulted in the lower foliar biomass found by Mann et al (1983) in the higher dbh class on the specific site where

sampling took place and which may not be generally representative of other sites. It could for instance be that inter-crown competition was occurring amongst the bigger trees. There could also be several reasons why foliar biomass increased so sharply from the 10 cm to 25 cm dbh classes. No mention was made as to whether the site was protected from browsing. It could therefore be that, if the smaller trees had been browsed, the figures might actually refer to foliar biomass from browsed canopies in the lower dbh classes and from canopies increasingly out of reach of browsing in the larger dbh classes. It could also be that the roots of the trees reached the water table when the dbh was between 10 and 20 cm. If that was the major reason for a sharp increase in foliar biomass from trees with a dbh greater than 15-20 cm, the results may not be applicable to other sites where the water table is reached by trees with different dbhs. The foliar biomass of trees with a dbh of 35 to 40 cm was 27 to 32.3 kg (?DM). Because of the absence of information on the previous management history of the trees, it is impossible to know how these data compare to yields from trees which are recurrently lopped since the size of the crown in protected and recurrently lopped trees is likely to vary considerably.

6. The data shown in Fig. 8.1.A (Bhimaya et al 1964) refer to trees growing on deep sandy loam soils near Jodhpur (mean P = 380 mm p.a.). The trees were lopped in December. The average dry matter (?DM) content of the leaves during the winter is c. 45% (Gupta et al 1974) which would result in dry leaf (?DM) yields of 4.7 kg for the dbh class 35 to 40 cm (average of 8 trees). However the values shown in Fig.8.1.A are based on two assumptions:

- i) that the original data on yield from the treatments in which trees were lopped annually referred to average annual yields and not the average cumulative yield from trees lopped annually over 4 years (see Table A.13.1).

ii) that the yield of the treatments in which the trees were given 4 years of rest between treatments referred to the yield obtained from lopping on year 4 and not to that same yield divided by 4 giving an average annual yield for trees lopped every 4 years.

It is appreciated that if these assumptions are correct, the results lead to the conclusion that the annual yield of annually lopped trees is greater than the mean "annual yield" from trees lopped every 4 years. This conclusion is contradictory to that of the authors who stated that "there is a substantial fall in the forage yield as a result of recurrent (annual) lopping (see Table A.13.1). However the text concerning "experimental layout" and "results and discussion" was so ambiguous concerning the number of years to which the yield data referred, that it is assumed that the authors misinterpreted their own data. The results obtained from making the assumptions which are adhered to here also agree with the results which Srivastava (1978) (see Fig.8.1.B) and Mann et al (1984) obtained (see below) and their recommendations that annual complete lopping results in greater average annual yields. The trees in this trial (Table A.13.1 and Fig. 8.1.A) had been subjected to severe lopping until 3 years prior to the start of the trial, and then allowed to develop "proper" crowns. Data for recurrently lopped trees (Table A.13.1) was not shown for individual years; since the yields in the first year are likely to have been greater than would be expected from trees which had previously been lopped, the figures for recurrently lopped trees are likely to be somewhat higher than would be expected under farm conditions for the same dbh class.

A separate lopping trial by the same authors was undertaken on a semi-rocky site with a shallow sandy soil near Jodhpur over the same years.

Table A.13.1. Original table as presented by Bhimaya et al (1964).

Fresh weight of leaves (kg) per tree of  
Prosopis spicegera (syn. cineraria)  
 (Average of 8 trees in each dbh class)

Treatments	Diameter classes (cm)			
	20-25	25-30	30-35	35-40
Recurrent lopping	6.3	6.8	7.7	10.4
Lopping after giving rest for 4 years	21.3	22.6	26.3	27.2
% increase over recurrent lopping	238.0	232.3	241.5	161.5

Table A.13.2. Original table as presented by Bhimaya et al (1964)

Yield of leaf fodder in kg per tree  
 (mean values, 1955-1958)

Treatment	Complete lopping bearing the central leading shoot	Lower 2/3rd crown lopped	Lower 1/3rd crown lopped
Yield	58.72	28.48	19.73

The average yields from 8 "fully grown" trees lopped each year (for 4 years in December (Table A.13.2) could be interpreted as being 26.4 kg (?DM - using the same conversion factor as above for FW to ?DM) or 6.6 kg (?DM) per tree per year. The description of the results was ambiguous enough that the figure given may be a mean for 4 years or a mean for annual yields. The past management of the trees was not described, although since they were in a classified "Afforestation" area, they may not have been lopped for a number of years prior to the trial - if ever - which would render the results irrelevant in terms of yields expected from trees traditionally lopped for fodder.

7. Fig. 8.1.B provides data from a lopping trial in Haryana state on a sandy site (mean P = 450 mm p.a.). The trees from the biggest dbh class - i.e. 25-30 cm - which were lopped completely each year in

December gave an average of 3.45 kg (FW) per tree, i.e. 1.6 kg (?DM) (average from 9 trees) (Srivastava 1978). No description of previous tree management was given. The trees were in a classified "Reserved" forest so that there is the possibility that the trees had previously not been lopped.

8. Lahiri (1976) stated that a "mature" tree of "moderate size" yields about 45 to 60 kg of dry (?DM) leaf forage.

9. Mann et al (1984) gave the results of a trial where the average annual yield from trees which were completely lopped (except for a few top shoots - 8 trees in each treatment) over 4 years was 57.3 kg (?W). The yields of trees which had only 1/3rd and 2/3rd of their canopy lopped annually were 15.9 and 22.4 kg (?W) respectively. No details were given concerning site characteristics, season of lopping, size of trees or previous tree management. It is possible that the trees had not been lopped prior to the trial - at least for some years - since the yield in the first year was 79.5 (?W) from completely lopped trees. However the mean annual yield over the next 3 years was still 49.9 kg (?W). The authors recommended the annual complete lopping (except for a few leading shoots) of Khejri trees for maximum forage yields.

10. Sharma et al (1981) investigated the effect of the season of lopping on fodder production of Khejri at Jodhpur (site conditions as in 6 above). The trees ranged in size from a dbh of 2.70 to 7.16 cm. Sixteen "naturally growing" trees (no information on tree spacing was given) were divided into 4 groups (4 trees of different dbhs in each group). The trees in each group were lopped annually and completely in the middle of February, May, August or November for 4 successive years. The first year's data were not included in the analysis since the trees had not been lopped previously and the canopy was therefore not representative of lopped trees. Table A.13.3 gives the results of the investigation.

Table A.13.3. Mean annual yield of foliage and lopped wood from trees harvested in different seasons (mean of 3 years and 4 trees in each group - Kg DM/tree); average height (cm) and dbh (cm) increment under the various treatments (see text for explanation) (derived from Sharma et al 1981).

Season of lopping

	Spring (February)	Summer (May)	Monsoon (August)	Winter (November)
Leaf yield (kg)	0.29	0.30	0.41	0.41
Wood yield (kg)	2.24	1.84	2.41	2.78
Initial height (cm)	240	240	250	285
Final height (cm)	313	275	281	355
Height increment (cm)	73	35	31	70
2nd year dbh (cm)	5.13	5.94	6.52	7.47
Final year dbh (cm)	8.70	7.46	8.72	10.25
dbh increment (cm)	3.57	1.52	2.20	2.78

Unfortunately the initial dbh of the 4 different groups of trees was not given so there is no way of being certain that the difference in yield shown with lopping in different seasons is in fact due to the season of lopping rather than to differences in the initial size of the trees. Table A.13.3 gives the average initial heights and the average dbh for the second year of the trial. It seems clear that the differences in the initial size (likely difference in the case of dbh) between groups is likely to have contributed considerably to the difference in yields between treatments. Individual year data did not show any trend in the influence of lopping in any particular season on the subsequent years' production; the samples were too small and the variation between years in any one group quite large, partly due to variations in precipitation between years. The authors stated that the yields are particularly influenced by the previous year's rainfall - however it should be emphasized that the trees were small

and may not have yet reached the water table. Although the authors suggested that the low production of lopped wood and foliage in spring and summer lopped trees is due to the detrimental effect of lopping during those seasons, there is also another possible explanation. Although the trees may start to come out in leaf during the spring, full foliage development may not occur until the monsoon. Similarly twigs are likely to go on growing from the spring until at least the end of the monsoon. From the evidence provided it may therefore be that spring and summer lopping may not be detrimental as such to future yields (although there is no evidence to conclusively prove or disprove this suggestion) but rather that the lopping was carried out at a time when the trees had not yet developed fully within the yearly vegetative cycle.

The authors also looked at the effect of the various lopping regimes on tree growth. They gave results (mean height and dbh over 3 years for each group) which they claim showed that "plant height and bole diameter (dbh) of the trees had been significantly affected by lopping in different seasons", with maximum height gains obtained with winter lopping. The statistical analysis of the data "shows highly significant variation both for years and seasons". However if one takes the increments during the trial period - i.e. the difference between final measurements and first year measurements for height and second year measurements for dbh (see table A.13.3), the differences are slight and probably not significant. The cause of the differences is more likely to have been due to differences in the initial size of trees before treatments. Further, the height of summer and monsoon lopped trees during the second year of the trial were 9 and 30 cm smaller than in the first year suggesting that the results concerning height increments may be of questionable value anyway - at least for summer and monsoon lopped trees.

11. Acharya (1980), referring to Bhimaya et al. (1964) (see 6 above) stated that a fully grown Khejri tree can provide 58 to 72 kg of dry leaves when completely lopped. He also stated that "a hectare of land can produce 1.9 quintals of fodder from tree loppings which is higher than the average forage yield per ha (of pasture) of 3.39 to 16.3 quintals under different rainfall and soil conditions reported by Ahuja (1977)" (one quintal = 0.1 tonne).
12. Paroda et al. (1981) stated that the trees of 7 to 8 metres of average height and 25 to 30 cm dbh yield on average about 9 to 10 kg of dry leaves.
13. Mann et al. (1980) stated that a moderate sized tree yields about 45 kg (?DM) of leaf fodder.



## APPENDIX 14

Fodder yield and biomass estimates of  
Zizyphus nummularia (Bordi).

The evidence concerning the fodder yields of Bordi indicate that they are highly variable. The following include all the published information which has been found concerning yields and biomass estimates.

1. A provenance trial of various Zizyphus species at Jodhpur (mean P = 380 mm p.a., on deep sandy loam soils with a hard pan at 120cm depth) included two provenances of Bordi. Their mean foliar biomass at harvest (cut at ground level) after 3 years of growth were 0.60 and 0.54 kg (?W) per bush respectively. The fuelwood biomass was 2.8 and 2.0 kg (?W) per bush (Muthana 1981, Saxena 1981b).
2. Saxena (1981b) stated that a well developed crown of Bordi produced 1.8 to 2.7 kg (DM) of foliage per year. He did not however describe the site on which one could expect such yields or whether this was for bushes which had been protected for a certain period.
3. Shankar's (1981) results (see Appendix 15) from biomass assessments of Bordi from a number of sites in W Rajasthan gives values ranging from 0.005 kg (DM) per bush on a gravelly grazing land to 0.102 kg (DM) per bush on a cultivated field. No indication was given concerning either the season of sampling or whether the bushes on the grazing land had been protected for the year of the investigation. The data suggested that the "yield" per bush on at least one of the grazing land sites may have been "leaf biomass remaining" at sampling time which would bear no relation to the actual yield during the year. The same may have applied to bushes on some of the other sites.

4. Kaul et al. (1963) harvested Bordi bushes from a site near Pali (mean P = 370 mm p.a., a shallow consolidated sandy site) which had previously been grazing land but had been protected for 3 years. The average leaf biomass at harvest (the season of harvest was not specified) was 150, 125 and 105 kg (?DM) per ha for shrub densities defined as 18, 14 and 11% canopy cover per ha respectively. This equates to 0.083, 0.089 and 0.095 kg for each m<sup>2</sup> of area covered by Bordi canopy. Although the information presented was not detailed enough to determine if these differences are significant, the results indicate that there may be a negative correlation between bush density and leaf biomass per unit area of bush canopy. A closer study at Shankar's results (3 above + Appendix 15) has revealed that on present evidence there is no obvious relationship between the leaf biomass data and percentage canopy cover from bushes on different sites (even if one takes into account likely differences in management of the bush). It is therefore impossible to convert Kaul et al's data to a figure of leaf biomass per bush.

5. Borha et al. (1981) stated that a Bordi bush is ready to provide fodder from the 3rd year onwards (on what site it is not specified) and may go on producing for more than 50 years. They also suggested that a moderately grown plant provides about 2.25 to 2.70 kg (DM) of leaves annually.

6. Saxena et al. (1981) found over a 5 year study period (including one year of average rainfall, two of subnormal and two of surplus rainfall, with a mean P of 430 mm p.a. over the 5 years - mean P for the 5 years = 430 mm) on the same site as 1 (above) that winter harvested bushes produced an average of 0.193 kg (DM) of leaf and 0.575 kg (DM) of bushwood per bush annually (table A.14). The results also show that winter harvesting results in the greatest combined yield of leaf and fuelwood. The authors did not provide annual data but mentioned that in the year of highest rainfall

(P = 642 mm) the foliage yield was 51% higher than the average over the 5 years. The study does not however reflect realistically the conditions found generally in W Rajasthan since the site had been protected for 10 years prior to the start of the investigation. The plants were said to be of "almost similar age groups".

Table A 14. Growth attributes of Z. nummularia from harvests made in different seasons (from Saxena et al 1981).

<u>Above ground biomass (gm DM)</u>			
<u>Season</u>	<u>Leaf</u>	<u>Shoot</u>	<u>Total</u>
Spring	73.3	348.5	421.8
Summer	40.0	338.2	378.2
Monsoon	252.0	248.6	400.6
Winter	193.1	574.9	768.0

APPENDIX 15

Leaf fodder and 'firewood' biomass of Zizyphus nummularia in different habitats and land use types (derived from Shanker 1981)

Habitat	Soil texture & depth (m) <sup>1/</sup>	Land use	Shrub density no/ha	Average canopy cover (m <sup>2</sup> /bush)	Average shrub height (m)	Shrub cover/ha (%)	Foliage yield Kg (DM)/ha	Foliage yield gm (DM)/m <sup>2</sup> canopy	Foliage yield gm (DM)/bush	Bushwood yield Kg (DM)/ha	Bushwood yield gm (DM)/bush	Bushwood to foliage ratio
Old alluvium	Clay loam 1.0	Cultivated field	1460	1.04	0.97	15.18	91.08	60	62	80.00	55	1.14 <sup>4/</sup>
Pediment plains	Gravelly 0.05	Grazing land	1250	0.09	0.16	1.12	6.36	57	5	23.72	19	3.73
Pediment plains	Loamy 0.25	Protected grassland	1500	0.44	0.81	6.64	42.75	64	29	98.00	65	2.29
Lower piedmont	Gravelly 0.01	Grazing land	170	0.66	0.85	1.12	15.44	138	91	63.83	38	4.13
Old alluvium	Sandy loam 0.65	Cultivated field	550	1.08 <sup>2/</sup>	0.62	5.88	49.99	85	91	117.31	213	2.35
Burried pediment	Silty loam 0.30	Cultivated field	2820	1.07	0.85	30.20 <sup>3/</sup>	142.33	47	50	323.10	115	2.27
Burried pediment	Sandy loam 0.60	Cultivated field	1660	0.63	0.91	10.46	169.20	162	102	147.00	89	0.87

- Notes:
- 1/ Shankar's (1981) table gave soil depth in cm; it is assumed the unit should have been "meters".
  - 2/ The original gave a figure of 0.18 m<sup>2</sup> canopy cover/bush and 5.88% canopy cover/ha: these appear to be inconsistent but since 5.88% matches the other entries in this column, it is assumed that 0.18 should read 1.07.
  - 3/ The original read 5.14. It is assumed that this was the figure which was most likely to be incorrect and was therefore changed to 30.2.
  - 4/ The original read 0.88 which was the ratio of foliage to bushwood - it has been corrected.

## APPENDIX 16

Density of Prosopis cineraria in W Rajasthan

A number of authors have given estimates of the density of Khejri trees in various areas of W Rajasthan.

1. The map of the density of Khejri for various areas of W Rajasthan (Fig. 8.4) appears to be based on the Shankar's (1980) tree densities shown in Tables A.16, a-e, which seem to refer to individual sample sites.

The data quoted in the tables were obtained during a "survey of arid shrublands of W Rajasthan". The sampling methodology for the survey was not described. However a number of points suggest considerable bias in the sampling strategy. Only one site (Table A.16,e) describes tree densities on arable land, yet 44% of W Rajasthan was under cultivation in 1971 and Khejri trees are said to be encouraged by farmers on cultivated lands (Mann et al 1980a, Saxena 1980). Shankar himself stated that in the district of Ganganagar, because of the difficulty of finding suitable sampling sites, "observations were recorded on the vegetation of the cemeteries and graveyards where the vegetation was like that of a reserved forest or a relic vegetation". Yet his map shows tree densities for more than half of Ganganagar district in the range 120-150 trees per ha. He also stated that in the Ganganagar - Bikamer - Churu region (Table A.16,e) Khejri was recorded only on 22 sites out of 70 sites sampled (the size of the sample plots was not mentioned) which should bring the mean tree densities down from those shown in Fig. 8.4 since Tables A.16, a-e show no plots with zero trees. His map gives a density value of 10 trees per ha for most of Jaisalmer district. This seems to be based on the only plot on which they found Khejri in Jaisalmer (Table A.16,a). The author did not state the lower size limit by which he determined whether to include or exclude a Khejri plant as a tree. Hence there is no way of knowing if these figures

refer to trees which are of a size which can be lopped or if they include young regeneration and "trees" which under continuous grazing/browsing develop "cushion" forms (Saxena 1980). In the 1976 CAZRI Annual Report, Saxena et al (1978) stated that for sites on gravelly and rocky pediments in the Nagaur district, "stray plants of P. cineraria (1-5/ha) in the form of cushion shaped bushes are also recorded". These sites are clearly not quoted in the subsequent relevant table (Table A.16.d) giving reason to question the meaning and relevance of the data provided by Shankar (1980).

2. Saxena (1980) provided some information on ranges of tree densities, heights and dbh classes for various site types in W Rajasthan. It is likely that the figures he provided refer to the range of maxima for different sites, since for younger alluvial plain sites the height of Khejri is stated to be 10-15 m and the dbh 40 cm.

3. Mann et al (1980) stated that the density of Khejri was 20-40/ha on cultivated flat alluvial plains (100-150 cm deep sandy loam to sandy clay loam soils, mean P = 350 -450 mm p.a.) and 40-120/ha on sandy undulating older alluvial plains of Nagaur and Ganganagar districts (2-4 m deep soils). The basis on which these figures were obtained was not described.

Site	Habitat	Present land use	Soil texture and depth (m)	Density (plant/ha)
Devikot (on Barmer Jaisalmer road)	Rocky pediment	Grazing land	Gravelly (0.5)	10
Khundala (Barmer-Sanchor road)	Flat (Older alluvial plains)	Reserved forest	Sandy loam (.60)	90
Hanthe talā (Barmer-Sanchor road)	Dune	Current fallow	Sandy (1.00)	20

Table A.16.a: Density of Khejri in the Barmer - Jaisalmer region (from Shankar 1981).

Site	Habitat	Present land use	Soil texture and depth (m)	Density (plant/ha)
Gandoj (Pali)	Lower pediment	Grazing land	Gravelly (0.60)	170
Netra (Pali)	Pediment plain	Grazing land	Gravelly (0.60)	20
Sindru (Pali-Sirohi)	Older alluvial flat	Waste land	Sandy, saline (0.90)	25
Akoti (Jalore)	Alluvial plains	Grazing land	Sandy-Clay loam (1.00)	60
Pali	Older alluvial flat	Grazing land	Sandy-Clay loam (1.00)	250
Chanod Basimada (Pali-Sirohi)	Older alluvial flat	Grazing land	Clay, saline (1.00)	20
Pali (Reserve Forest) (Pali-Jalore)	Older alluvial flat	Reserved Forest	Sandy clay loam (1.00)	100
Loonawas (Pali)	Older alluvial (Low lying)	Grazing land	Sandy loam (1.00)	10
Araba (Pali-Jalore)	Older alluvial flat	Grazing land	Clay loam (1.00)	10
Asotra (Pali-Jalore)	Older alluvial flat	Grazing land	Clay loam (1.00)	130
Asoda (Pali-Jalore)	Older alluvial flat	Grazing land	Sandy clay loam (1.00)	120

Table A.16.b: Density of Khejri in the Pali - Sirohi - Jalore region.

Site	Habitat	Present land use	Soil texture and depth (m)	Density (plant/ha)
Chaba (Shergarh-Shiv road)	Sandy undulating plains	Old fallow	Sandy (0.5) Gypsum	20
Solankiawas (Shergarh-Shetrava road)	Sandy undulating plains	Grazing land	Sandy (+ 1.00)	10
Shergarh (Shergarh-Shetrava road)	Sandy interdunal plains	Waste land	Sandy (+ 1.00)	20
Nachna (Pokaran-Nachna road)	Sandy plains	Grazing land	Sandy (+ 1.00)	5
Gajner (Kolayat-Bikaner road)	Pediment plains	Grazing land	Gravelly (0.10)	6
Gajner (Wild life Sanctuary road)	Pediment plains	Reserved forest	With sand deposit (0.10)	33
Khari (Kolayat-Bikaner)	Pediment plains	Grazing land	With sand deposit (0.15)	20
Golari (Kolayat-Bikaner)	Pediment plains	Old fallow	With sand deposit (0.50)	10
Kolayat (Near Kolayat-Bikaner)	Pediment plains with heavy sand deposit	Reserved forest	Sandy (0.3)	21
Kichan (Phalodi)	Pediment plains with heavy sand deposit	Old fallow	Gravelly (0.5)	7
Luna (Kolayat-Phalodi)	Sandy undulating	Old fallow	Sandy (+ 1.00)	35
Hindasar (Kolayat-Phalodi)	Sandy plains	Old fallow	Sandy (+ 1.00)	32
Hindasar (Kolayat-Phalodi)	Sandy undulating plains burried pediment	Old fallow	Sandy (+ 1.00)	42
Padiyal Raner (Phalodi-Nagaur)	Sandy plains	Old fallow	Sandy (+ 1.00)	10
Ghevra (Phalodi-Osian)	Older alluvial flat with sand deposit	Old fallow	Sandy (+ 1.00)	30
Khabra khurd (Osian-Chirai road)	Older alluvial flat with sand deposit	Old fallow	Sandy (+ 1.00)	20

Table A.16.c: Density of Khejri in the Shergarh, Pokaran, Koloyat, Phalodi and Osian region.



Site	Habitat	Present land use	Soil texture and depth (m)	Density (plant/ha)
Barnad (Nagaur-Nokha-Bikaner)	Older alluvial flat	Grazing land	Sandy loam (1.00)	10
Jakhora (Nagaur-Nokha-Bikaner)	Sandy undulating plains	Cultivated fallow	Sandy loam (1.10)	160
Uncharua (Nagaur-Nokha-Bikaner)	Older alluvial flat	Grazing land	Sandy loam (1.00)	40
Chuna (Nagaur-Nokha-Bikaner)	Older alluvial flat	Grazing land	Sandy loam (1.00)	10
Katothi (Nagaur-Nokha-Bikaner)	Older alluvial plains	Grazing land	Clay loam (1.00)	40
Thibri (Nagaur-Nokha-Bikaner)	Older alluvial plains	Cultivated fallow	Sandy loam (1.00)	30
Rajas (Nava Tehsil)	Older alluvial plains	Cultivated fallow	Sandy loam (1.00)	56
Bansa (Nava Tehsil)	Older alluvial plains	Cultivated fallow	Sandy loam (1.00)	30
Ghetwa (Nava Tehsil)	Older alluvial plains	Cultivated fallow	Clay loam (1.00)	30
Rajliya (Nava Tehsil)	Older alluvial plains	Cultivated fallow	Sandy loam (4.00)	170
Degana (Nava Tehsil)	Older alluvial plains	Cultivated fallow	Sandy clay loam (0.9)	60
Parbatsar (Nava Tehsil)	Older alluvial plains	Cultivated fallow	Sandy loam (0.8)	65

Table A.16.d: Density of Khejri in the Nagaur - Bikaner region.

Site	Habitat	Present land use	Soil texture and depth (m)	Density (plant/ha)
Kudsu (Nokha-Udasar)	Sandy undulating plains	Old fallow	Sandy loam (+ 1.00)	40
Ranisar (Ratangarh-Churu)	Low dunes	Old fallow	Sandy (+ 1.00)	10
Churu	Sandy undulating plains	Grazing land	Sandy (+ 1.00)	20
Sawai (Sardar Shaher-Dungargarh)	Sandy undulating plains	Grazing land	Sandy (+ 1.00)	70
Bhadasar (Sardar Shaher-Dungargarh)	Dunes	Arable land	Sandy (+ 1.00)	30
Bramsar (Sadur Shaher-Hanumangarh)	Flat plains	Grazing land	Sandy (+ 1.00)	10
Hariyasar (Sardar Shaher-Hanumangarh)	Low dunes	Grazing land	Gypsiferous loam (0.60)	80
Narang deshar (Hanumangarh)	Alluvial plains	Grazing land	Loamy (+ 1.00)	40
Kishanpur (Ganganagar)	Older alluvial flat	Grazing land	Loamy (+ 1.00)	250
Netewalis (Ganganagar)	Older alluvial flat	Waste land	Loamy (+ 1.00)	130
Suratgarh (Ganganagar-Suratgarh)	Sandy undulating plains	Waste land	Sandy (+ 1.00)	50
Rangmahal (Suratgarh-Hanumangarh road)	Older alluvial plains	Waste land	Loamy (+ 1.00)	100
Hariyasar (Suratgarh-Lunkaransar road)	Sandy undulating plains	Grazing land	Sandy (+ 1.00)	10
Phuldeshar (Lunkaransar)	Sandy undulating plains	Grazing land	Sandy (1.00)	10
Lunkaransar	Sandy plains	Grazing land	Sandy loam (1.00)	10
Khera (Lunkaransar)	Sandy plains	Grazing land	Sandy loam (1.00)	150
Palana (Bikaner-Nagaur road)	Sandy undulating plains	Grazing land	Sandy (1.00)	20
Alai (Bikaner-Nagaur road)	Older alluvial, low lying flat	Grazing land	Clay-loam (0.90)	20
Jamsar (Suratgarh-Lunkaransar)	Older alluvial flat	Grazing land	Loamy (0.70)	110
Bamariya (Lunkaransar-Bikaner)	Older alluvial flat	Grazing land	Loamy (0.45)	20
Kasturia (Lunkaransar-Bikaner)	Sandy undulating plains	Grazing land	Sandy (1.00)	10
Jamsar (Lunkaransar-Bikaner road)	Low dunes	Waste land	Sandy (1.00)	10

Table A.16.e: Density of Khejri in the Ganganagar - Bikaner - Churu region.

## APPENDIX 17

Height, dbh and age relationships of *P. cineraria*

No published information seems to exist giving dbh to age relationships for Khejri. Since it is important to know what this relationship is, it has been necessary to attempt to derive such a relationship from height to age and height to dbh relationships.

Fig. A.17.1. gives a curve relating dbh to height derived from data (x) given by Mann et al (1983) and which were obtained from trees growing on a flat alluvial plain (see Appendix 13.5). The points marked by "o" are from Bhimaya et al's (1964) data from trees growing on a semi-rocky site with sandy shallow soils near Jodhpur (see Appendix 13.6).

Fig. A.17.2. gives a curve relating height to age for trees grown under different soil working treatments. The site was at Jodhpur (mean P = 380 mm p.a.) on a flat area of deep sand with a hard pan at 120 cm depth (Muthana et al 1976). An extra hypothetical curve has been fitted on Fig. A.17.2 on the assumption that the levelling off of most curves from year 7 onwards may have been due to inter-tree competition since the trees were planted at 2 m spacing. Khejri trees usually grow at wider spacing than 2 m under natural conditions and in farmers fields. The curves drawn by Muthana et al (1976) and Muthana (1980) and shown in Fig. A.17.2 were derived from points which represented the average values from 4 trees. It is acknowledged that there is no evidence to suggest that the relationship should be as indicated by the hypothetical curve. Nevertheless it has been drawn to indicate that the recommendations made by various authors concerning the desirable age of first lopping (e.g. 8 years, Saxena 1981b; 10 years, Bohra et al 1980) are likely to be overoptimistic for rainfed sites.

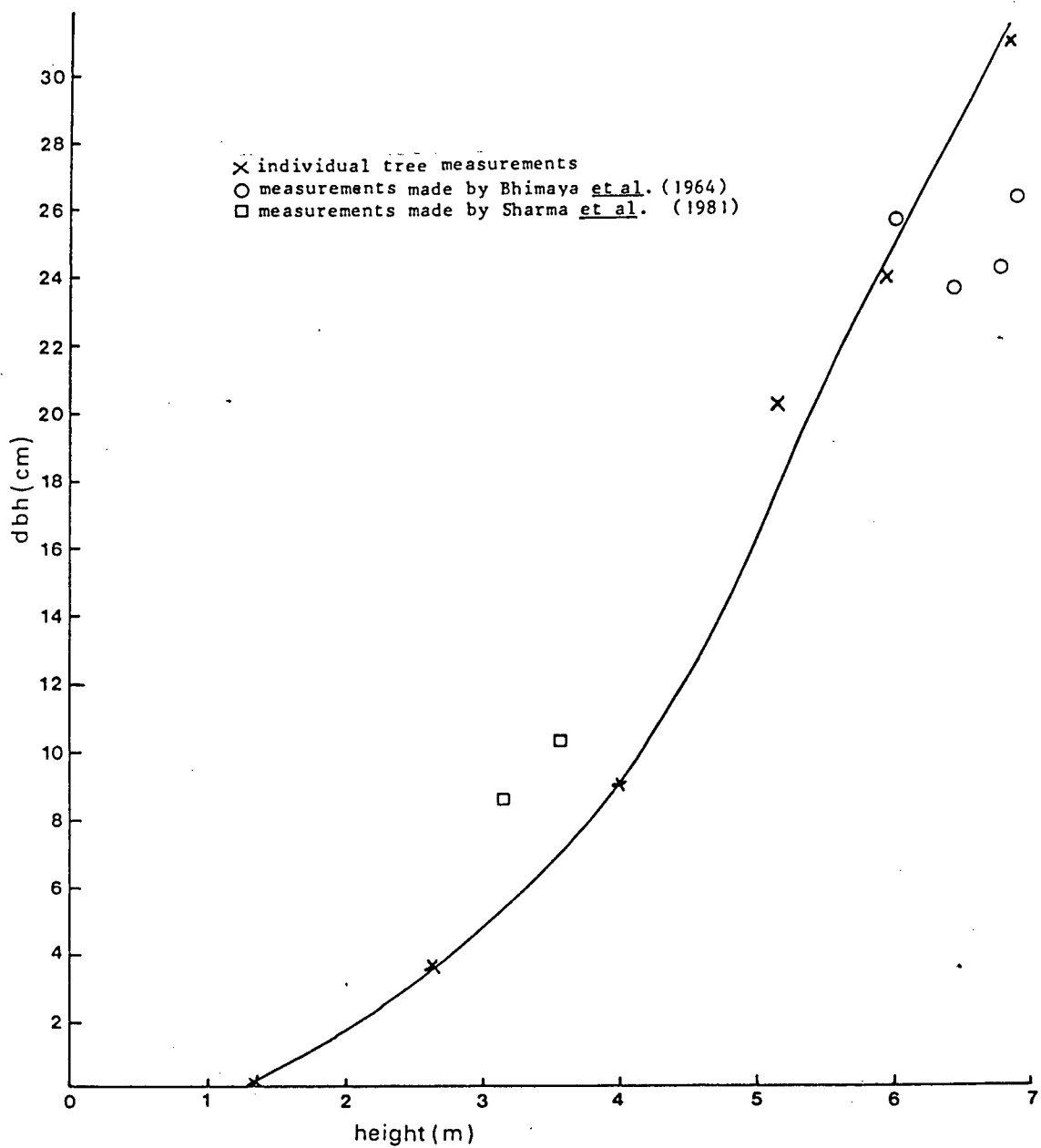


Fig. A.17.1 Height to dbh relationship of Khejri (derived from Mann et al 1983).

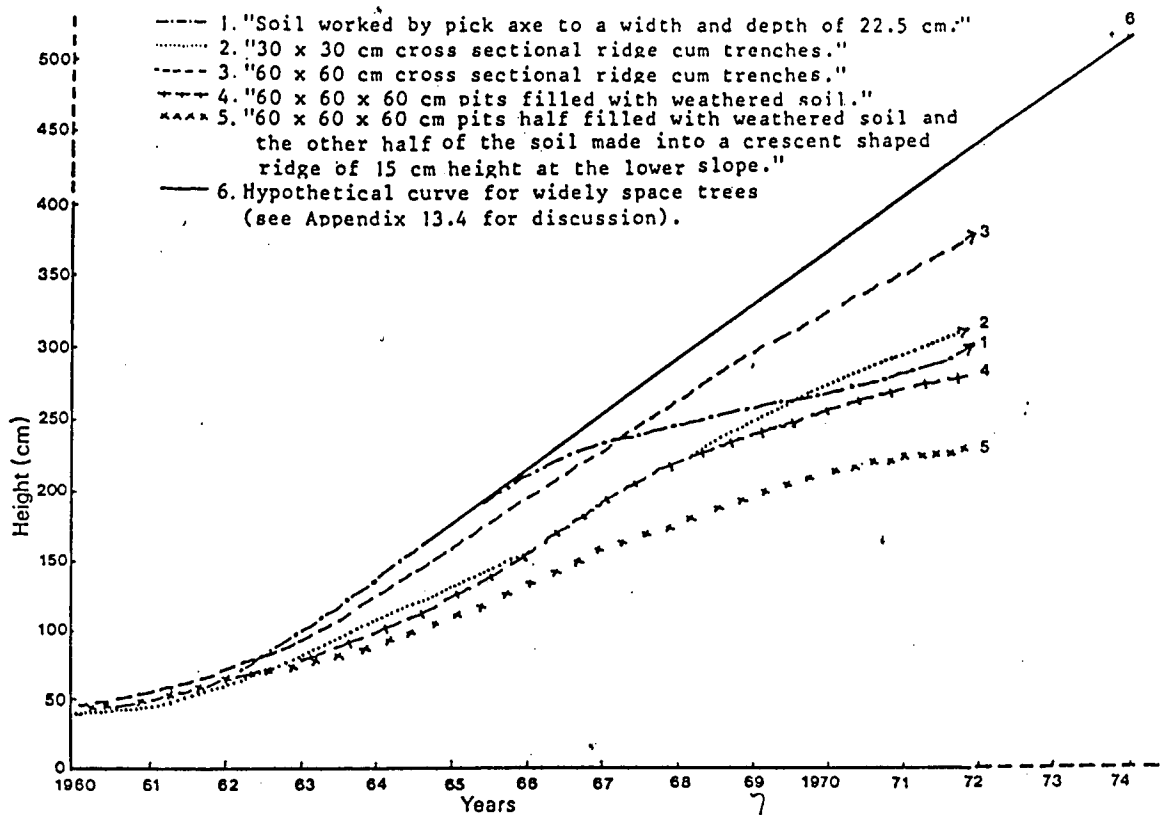


Fig. A.17.2. Height growth of *Prosopis cineraria* under different soil working treatments. (Jodhpur 1960-1972)(from Muthana et al. 1976).

The recommendation has been made by Srivastava (1978) that trees should only be lopped once they have reached a dbh of 15 cm. However if the hypothetical curve is correct, a height of about 5 m should be reached before first lopping and according to the hypothetical curve this would require around 14 years of growth. The site on which Muthana's data were obtained was a good site and the trees had been regularly weeded.

Assuming the hypothetical curve is realistic, it would take 6 years before the trees are out of reach of goats, cattle and sheep and 8 years before they are out of reach of camel.

## APPENDIX 18

Foliar yields and biomass of dry zone  
fodder trees from areas other than N.W. India.

It was thought relevant to examine data for foliar yields or biomass from other dry zone small leaved legume tree species occurring in other parts of the world to determine the likely range of values which could be expected for Khejri yields.

1. Piot et al (1980) harvested the leaves of a number of fodder trees in the Sahelian zone of Bourkina Fasso (mean P = 438mm p.a. for the area surveyed). Table A.18.1. gives the foliar biomass of the 3 small leaved legume species which they sampled (Acacia laeta R. Br. ex Benth., Acacia tortilis (Forsk.) Hayne and Acacia seyal Del.). The season of sampling was at the time of maximum vegetation development. The diameter classes refer to diameter at ground level.

Table A.18.1. Foliage standing crop (Kg ?DM/tree) of 3 Acacia species in the Sahelian zone of Bourkina Fasso (from Piot et al 1980).

<u>Species</u>	<u>Stem Diameter (cm at stem base)</u>							
	<5	5	10	15	20	25	30	35
<u>A. laeta</u>	0.15	0.50	2.20	2.50	3.10	3.50		
<u>A. tortilis</u>	0.05	0.25	0.30	0.70	1.10	1.20	1.60	
<u>A. seyal</u>	0.06	0.52	1.30	1.70	3.80	6.90	8.00	8.50

The authors did not state if the trees they harvested were likely to have been browsed or lopped in the years preceding the survey.

The data are based on samples of one tree for each species in each diameter class.

2. Fig. A.18.1. shows diagrammatically the results of the foliage harvest of Acacia senegal (L) Willd. in the area of Fété-olé of N. Senegal (mean P = 350 mm p.a. but only 33 mm in the year prior to sampling) (Poupon 1976). The values for stem diameter in Fig. A.18.1

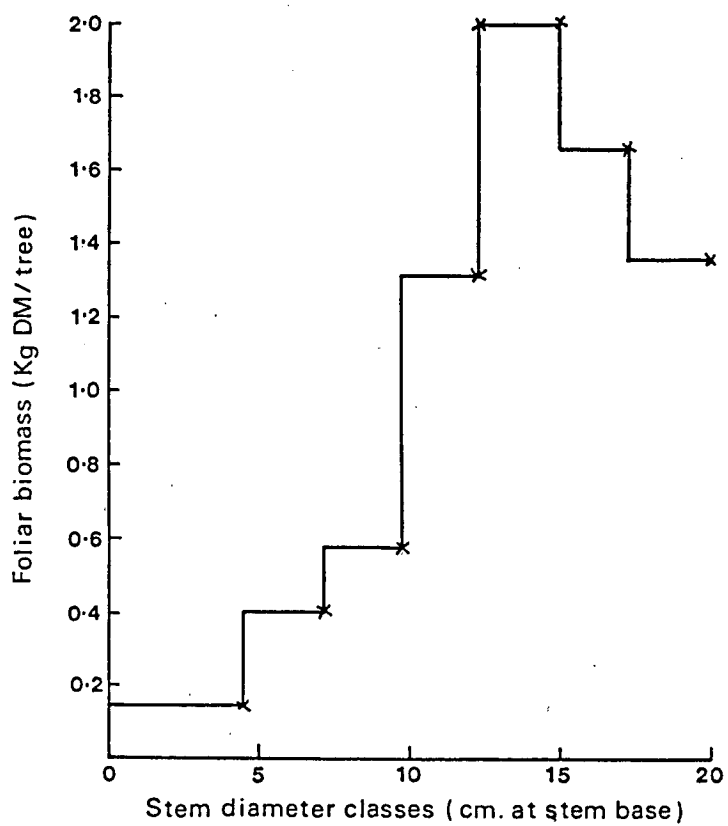


Fig.A.18.1 Foliar biomass of *Acacia senegal* in North Senegal, according to stem diameter classes (derived from Poupon 1976).



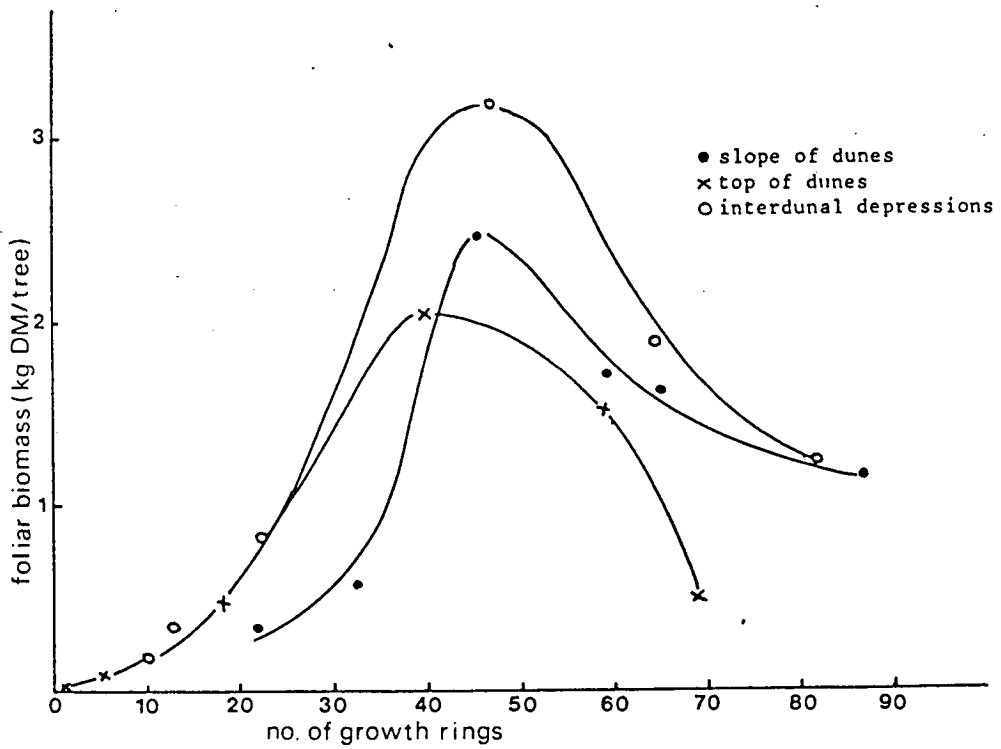


Fig A.18.2 Foliar biomass of *A. senegal* for trees of different age growing on different sites in N. Senegal (from Poupon 1976).

were obtained from a graph in Poupon's paper which related the stem diameter to the number of growth rings. Poupon's data on foliar biomass was given for trees in different classes based on growth ring counts (a sample of 2 to 3 trees in each class). Fig. A.18.2 (from Poupon 1976) also shows that foliage biomass varies within an age category (number of growth rings) according to the site: a higher foliar biomass was obtained by trees in interdunal areas compared to trees located on a dune. The author did not specify if the trees had been protected over a number of years prior to the measurements.

3. Cisse (1980) weighed foliage from felled trees of Acacia albida Del. and Acacia seyal Del. in Mali. No information was given concerning the site, the local precipitation regime, the season of harvest or the likely previous management of the trees. The values he obtained for trees of different stem diameter classes (5 trees in each class and diameter measured at 40 cm above ground) are shown in Table A.18.2. A. albida is known to be a phreatophyte (Charreau et al. 1971).

Table A.18.2. Foliar biomass from two Acacia species in the Sahelian zone of Mali (Kg DM per tree). (The stem diameter classes are converted from circumference classes).

	<u>Stem diameter (cm at 40 cm height)</u>						
	9.6 - 12.7	12.7 - 15.9	15.9 - 19.1	19.1 - 22.3	22.3 - 25.5	25.5 - 28.7	28.7 - 31.8
<u>A. albida</u>	1.80	3.11	4.20	6.45	9.02	10.18	14.01
<u>A. seyal</u>	2.33	3.61	3.41	7.24	10.17	13.44	-

4. Maghembe et al (1984) measured the foliage biomass of Prosopis juliflora near Mombasa, Kenya. The site was a reclaimed limestone quarry and the mean annual precipitation over the years of growth of the trees (6 years) was 1220 mm. However the tree roots may have reached the water table in the years prior to sampling. The spacing between trees was not documented and the results are based on single

tree samples of the following sizes (diameter, at ground level).

Basal diameter (cm)	10.5	15.4	20.4	25.0	31.7
foliar biomass Kg(DM)/tree	1.46	5.23	14.47	10.33	15.69

5. Pressland (1975) measured the foliar biomass of Acacia aneura F. Muell. trees of varying stem diameter classes (measured at 30 cm height) near Charleville in S.W. Queensland. The results are given in Fig. A.18.3 which gives the curve from his calculated regression between stem circumference and foliar biomass. The vertical bars indicate the 95% prediction intervals for selected tree diameters. The points refer to individual tree data. The site on which the trees were growing was not described, but the mean annual precipitation at Charleville is 467 mm (Burrows 1978). The stand was described as "open forest" and the trees had probably not previously been lopped.

6. Fig. A.18.4 shows the estimated annual production of leaves and pods of Prosopis tamarugo in the Pampa del Tamarugal in Chile. There is virtually no precipitation (Salinas et al 1971) but the trees are phreatophytes relying for much of their moisture uptake on the water table which lies at a depth varying from 2 to 10 m. The data on leaf production was obtained by laying a large number of trays for a whole year under trees of varying ages and canopy sizes (the trays were emptied every 30 to 60 days). It is not clear how the curve was derived from the original data since the variation in foliar production was confounded by variation in spacing between trees (from 6 x 7 m to 20 x 20 m), in canopy width, in depth of the water table and in the salinity levels of the water (from 0.750 to 3.00 mg/l). It was not stated how dry or fresh the leaves were but it seems as if they were at least partially air dried. It has not been possible to derive the relationship between stem diameter (measured at 1 m height) and foliar production (or stem diameter and age) from the original data. The original data showed one 9 year old

Notes: ● = individual tree measurements.  
 the line has been drawn from a calculated regression and the vertical bars indicate the "95% prediction intervals" for selected tree diameters.

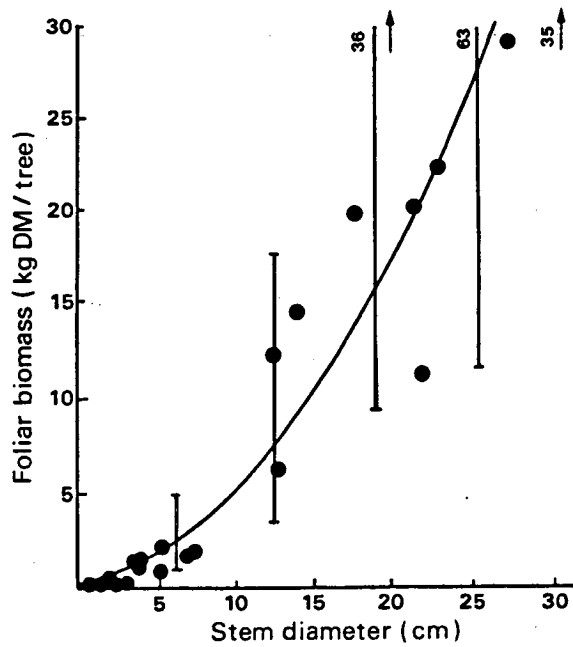


Fig. A.18.3 Foliar biomass of *Acacia aneura* trees of different sizes in S.W. Queensland (stem diameter of 30cm. above ground) (derived from Pressland 1975).

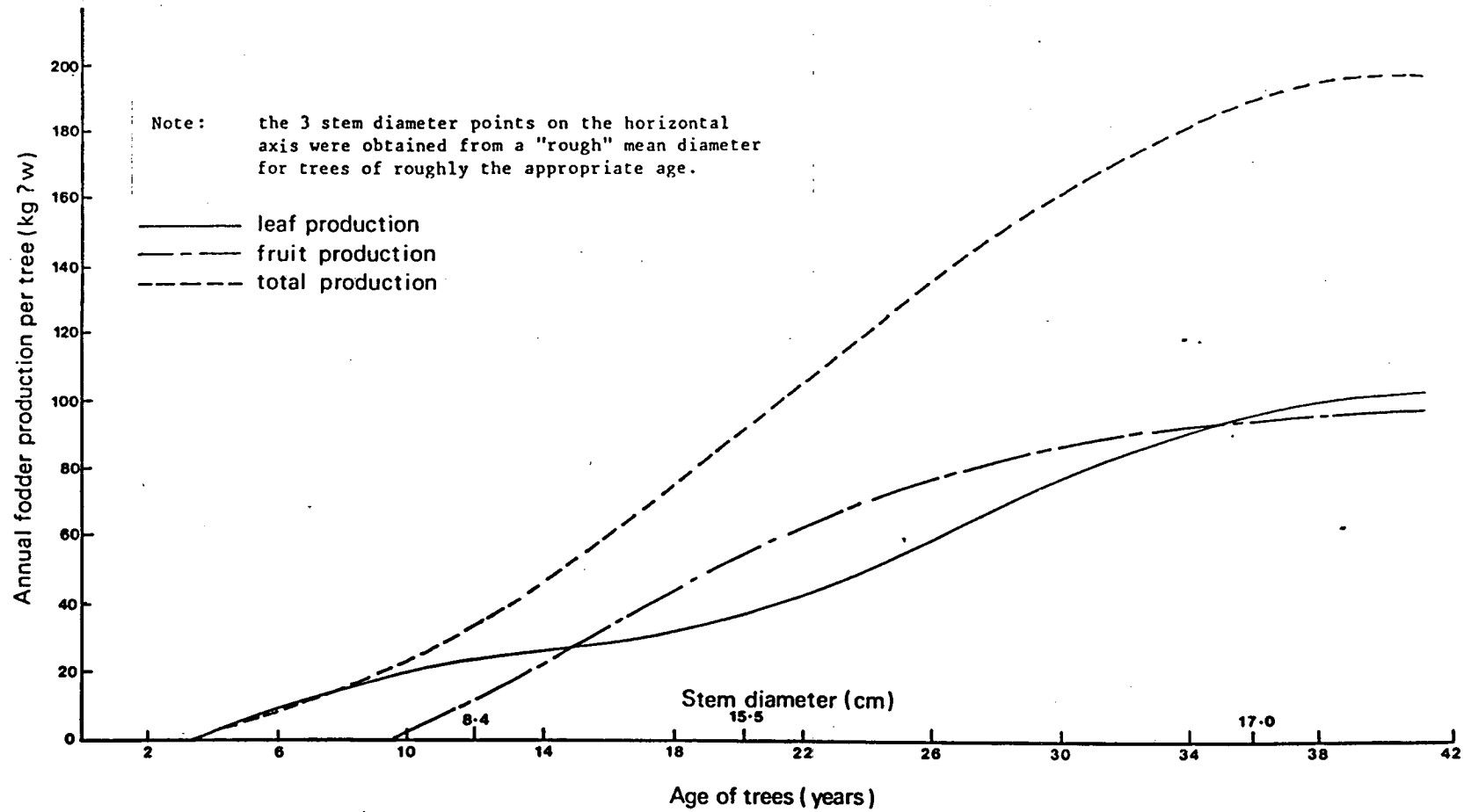


Fig. A.18.4. Annual fodder production of Prosopis tamarugo according to the age of the trees (Salinas et al 1979 and Habit et al 1981).

tree with a foliar production of 38.02 kg (?W) and a 32 year old tree within a production of 36.21 kg (?W). The more recent treatise on P. tamarugo (Habit et al 1981) does not provide any further data on foliar production and relies on Salinas et al (1971) for information concerning foliar production.

7. Measurements which have been made of the foliar production of Acacia karroo in the Eastern Cape (Aucamp et al 1983) are not appropriate since they refer only to foliage production up to a height of 1.5 m (browse reach).

## APPENDIX 19

Densities of Zizyphus nummularia in W Rajasthan

The following four tables are from Shankar (1981) who suggested that they gave the average density of Bordi for various habitats of W Rajasthan. However the figures were obtained during the same survey as described for Khejri (Appendix 16) and therefore the same misgivings apply concerning the extent to which they are realistically representative of Bordi densities.

Table A.19.1. Density of Bordi on older alluvial plains of nine districts of W Rajasthan.

District	Range	Mean	No. of sites sampled
Nagaur	30-180	720	4
Sikar	10-160	78	4
Churu	10-1270	405	4
Bikaner	390	390	1
Ganganagar	210	210	1
Jaisalmer	65	65	2
Jodhpur	265-750	471	4
Pali	10-470	128	4
Jalore	10-160	76	5

Table A.19.2. Density of Bordi in various habitats in W Rajasthan.

Habitat	Range	Mean	No of sites sampled
Older alluvial plains	10-1880	373	31
Sandy undulating plains	10-1160	206	28
Sandy buried pediments	10-210	78	6
Interdunal sandy undulating plains	10-150	80	2
Sandy undulating pediment plains	10-580	95	17
Upper pediments	30-440	175	4
Lower pediments	10-90	50	2
Gravelly plains	10-270	105	4
Hilly/rocky areas	30-50	40	2
Low dunes	10-250	92	6
River beds	0-10	10	1

Table A.19.3. Density of Bordi on different soil types of W Rajasthan

Soil type	Range	Mean	No. of sites sampled
Sandy	5-1160	122	74
Loamy	10-1880	478	15
Sandy loam	10-1640	453	12
Clay loam	10-170	64	6
Gravelly	10-440	109	16

Table A.19.4. Density of Bordi on different land use types in W Rajasthan.

Land use	Range	Mean	No. of sites sampled
Grazing lands	5-1600	214	93
Wastelands	10-360	160	9
Cultivated fallows	5-1640	212	21
Reserved pastures	30-750	345	4



## APPENDIX 20

Feed requirements of Adult Cattle Units (ACUs)

Mann et al (1975) stated that an ACU in the N.W. arid zone of India requires 2.5 tonnes (?DM) of forage p.a. (i.e. 6.9 kg per day). This figure has been accepted by other authors from CAZRI and elsewhere in Rajasthan. However because it has not been possible to find out how this figure was obtained and because no indications were given as to the level of production which such an intake could sustain, it was thought necessary to look at a number of estimates of forage requirements and forage intakes from different parts of the tropics for different types of livestock.

The following give various estimates of the feed requirements of cattle, sheep, goats, buffalo and camel with comments on the level of production associated with the particular feed requirements. At the end of each estimate, the figure has been converted to the equivalent feed requirement for an ACU. This has been done with the appropriate conversion factor using the metabolic weight ( $W^{0.75}$ ) of animals when the body weight of the livestock concerned was given. Where a figure of requirement was given as a percentage of body weight, the original figure was multiplied up to 300 kg for cattle. In the case of small stock the figure was converted to a live weight of 35 kg (see Appendix 7A) and then converted to an ACU using the metabolic weight conversion.

(i) Cattle and buffalo

1. Boudet et al (1968 - in Le Houerou et al 1977) estimated that in the Sahel, the maintenance needs of a mature zebu weighing 250 kg was 6.25 kg (?DM) per day (i.e. 7.2 kg ?DM per ACU).

2. Lander (1949 - in Mohns 1981) determined that the daily maintenance forage requirement of the water buffalo in India was 5.0 to 7.0 kg per ACU.

3. Wilson (1982a) found amongst the pastoral systems in Mali that cows with a mean liveweight of 244 kg had an average daily dry matter intake (average of 12 months) of 6.32 kg (i.e. 7.4 kg ?DM per ACU). They also referred to investigations from elsewhere which had given the following intake (?DM) figures;

Nigeria, 2.3 to 2.5% of bodyweight i.e. 6.9 - 7.5 kg per ACU

Zimbabwe, 1.5 to 1.9% of bodyweight i.e. 4.5 - 5.7 kg per ACU

Botswana, 1.5 to 2.1% of bodyweight i.e. 4.5 - 6.3 kg per ACU

They suggested that the higher figure obtained for cattle in Mali was due to the higher energy expenditure associated with transhumant cattle which have to walk long distances between grazing areas and watering points.

4. de Leeuw et al (1972) referred to results from Shika Research Station in Nigeria where the daily "normal intake" of a standard cow unit (272 kg) was 6.8 kg (?DM), and this level of intake was required for maintenance and "some normal growth" (i.e. 7.3 kg ?DM per ACU).

5. Pratt et al (1977) stated that the average daily intake (?DM) in feeding trials with East African zebu cattle was 1.5 to 3% of liveweight (i.e. 4.5 to 9 kg ?DM per ACU). The intake level varied particularly according to the age of the animal and the nature of the feed. For a zebu ACU they suggested a daily allowance of 7.3 kg (?DM) to allow for "growth and fattening".

6. Sen et al (1978) stated that the Metabolizable Energy requirements reported by Indian workers for "adult non-producing" cattle ranged from 98 to 131 Kcal per kg  $W^{0.75}$ . Since the nutritive value of most straws, hays and roughages range from 1.6 to 2.0 Mcal per kg of dry matter, the daily maintenance requirements of a non-producing ACU would therefore range from 3.5 to 5.9 kg (?DM). The authors however stated that cattle can generally eat about 2.0 to 2.5% (?DM) of their bodyweight (i.e. 6 to 7.5 kg ?DM per ACU).

The maintenance requirement of the lactating animal is 11% higher (for a production level of one kg of milk per day with a 3% fat content) and for normal working bullocks 30% higher. Hence, assuming generously that the intake level in cattle in W Rajasthan is 20% higher than that required for a maintenance ration, the daily feed intake would range from 4.2 to 7.1 kg (?DM) per ACU.

The authors themselves assumed an energy requirement for maintenance of 8.5 Mcals per ACU (a high value in the range which they quoted). This would result in an intake of 4.25 to 5.3 kg (?DM) for maintenance assuming the same range of quality feed as above and an intake of 5.1 to 6.4 kg (?DM) for the levels of production suggested above.

7. Ray (1978) stated that a dry cow usually consumes a palatable fodder of good quality at the daily rate of 2% (?DM) of its body weight and that cows in milk consume 2.5 to 3.0% of their weight (i.e. 6 kg ?DM per dry ACU and 7.5 to 9 kg ?DM per day for ACUs in milk). Although these figures are meant to refer to Indian conditions, it is not clear what investigations these data were based on since 6 out of 7 of the references quoted are from industrialized nations.

8. Piot et al (1980) suggested that for the Sahelian zone of Bourkina Fasso, the daily maintenance feed requirement is 2.3 to 2.8 "Feed Units" for 250 kg cattle walking short and long distances respectively. Since the average yearly value of one kg of consumable dry matter is equivalent to 0.4 Feed Units in the Sahel (Le Houerou et al 1977), the dry matter (?DM) requirement is therefore 5.75 to 7 kg (i.e. 6.67 to 8.08 kg ?DM per ACU).

(ii) Camels

9. Lusigi (1981) stated that the average daily intake for adult camels in the arid zone of N. Kenya is 1.73% of their body weight. Simpkin (1983) found for the same area that adult camels weighed an average

380 kg so that the intake would be 5.5 kg per ACU.

(iii) Goats and Sheep.

10. Sengar (1980 in Mohns 1981) reviewed Indian research on dairy goats and stated that they need 80 gr (?DM) per kg of their metabolic weight daily (i.e. 5.8 kg ?DM per ACU).

11. Devendra et al (1982) suggested that a 35 kg goat needed 0.6 kg (?DM) of feed for a maintenance ration in the tropics, and 1.1 kg (?DM) for production (i.e. 3.0 to 5.5 kg ?DM per ACU).

12. Kalla et al's (1980) data on total feed requirements for sheep in W Rajasthan have been discounted as it is not clear if they referred to FW or ADM.

13. Wilson (1982a) found that in transhumant herds of goats and sheep in Mali, the mean value for dry matter intake was 2.6% of body weight per day (i.e. 4.6 kg ?DM per ACU).

14. Lusigi (1981) stated that the average daily dry matter intake of sheep and goats in the arid zone of N. Kenya was 2.43% of body weight (i.e. 4.26 kg ?DM per ACU).

15. CAZRI (1983) stated that a 45 kg adult goat in W Rajasthan has an average daily intake of 1.5 kg (?DM). Sheep have an average dry matter intake of about one kg (and they weigh on average about 35 kg, Sen et al 1981) (i.e. goats and sheep have an average intake of 6.2 and 5 kg ?DM per ACU respectively).

16. Ghosh et al (1980) stated that the average daily dry matter intake of goats and sheep (which are both stated to weigh about 35 kg) is 1.5 and 1.0 kg respectively (7.5 and 5.0 kg ?DM per ACU respectively).

17. Ray (1978) suggested that goats and sheep eat 0.3 kg (?DM) daily per 10 kg of bodyweight (i.e. 5.2 kg per ACU). He also stated that the nutrient requirements of adult ewes which are not lactating and not more than 15 weeks into pregnancy have a maintenance requirement of 0.95 kg (?DM) for a 35 kg bodyweight (i.e. 4.8 kg ?DM per ACU).

## APPENDIX 21

Calculations and assumptions concerning the fodder WP densities required to meet the fodder shortfall.

The aim of the following calculations is to determine the average fodder WP density which would be required to meet the fodder shortfall during an average rainfall year if all livestock remained in the area over the whole year. The assumptions are:

- i) the livestock consume all the available pasture production (89% utilization - see Table 8.5);
- ii) the maximum area where fodder WPs could grow covers 17.853 M ha (see Table 8.6);
- iii) one third of the total area of W Rajasthan falls in the rainfall zones with less than 200 mm p.a., 200-300 mm p.a. and more than 300 mm p.a. respectively;
- iv) the average fodder yield of productive Khejri trees is therefore 3.17 kg (DM p.a.) and that of a Bordi bush 0.14 kg (DM p.a.);
- v) other fodder WP species are equivalent in yield to Khejri and Bordi where these are substituted.

The fodder shortfall which fodder WPs need to meet is 7.41 M tonnes (?DM) or 0.415 tonnes (?DM)/ha.

115 Khejri trees would produce 0.365 tonnes (DM)/ha

300 Bordi bushes would produce 0.042 tonnes (DM)/ha

Total 0.407 tonnes (DM)/ha.

## APPENDIX 22

Calculation of a possible browse demand by camel and goats on "grazing" lands.

1. Since no quantitative information on the diet preferences of browsers under natural range conditions is available from W Rajasthan, it was thought relevant to calculate what the browsing demand might be during the monsoon from the grazing lands of the area on the basis of data collected in a similar climatic zone in N Kenya (Lusigi 1981). While the figures on the estimated proportion of browse in the total diet represented averages over the year, since Lusigi stated that small ruminants obtained more of their diet from browse during the rainy season, the averages are thought to be conservative values. The figures also represented estimates rather than actual quantities since they were derived from observation on time spent feeding on various plants (Said et al. 1983).

a. Possible camel browsing demand/grazing ha: 0.08 camel ACU/ha (from Appendix 6 and 7a); 90 grazing days; daily requirement for production of either (1) 6.4 kg (DM)/ACU (assumed mean requirement for ACUs from section 8.4.1); or (2) 5.5 kg (DM)/ACU (intake level for camels in N Kenya); browse comprises 78% of the diet.

ie. (1)  $0.08 \times 90 \times 6.4 \times 0.78 = 35.9 \text{ kg(DM)}$

(2)  $0.08 \times 90 \times 5.5 \times 0.78 = 30.9 \text{ kg(DM)}$

b. Possible goat browsing demand/grazing ha: 0.117 goat ACU/ha; 90 "grazing" days; daily requirement for production of either (3) 6.4 kg/ACU (assumed mean for ACUs from section 8.4.1); or (4) 5.2 kg/ACU (mean intake levels for goats from Table 8.4); browse comprises 53% of the diet.

ie. (3)  $0.117 \times 90 \times 6.4 \times 0.53 = 35.7 \text{ kg(DM)}$

(4)  $0.117 \times 90 \times 5.2 \times 0.53 = 29.0 \text{ kg(DM)}$ .

2. A 17 day feeding trial with goats in W Rajasthan showed that goats (Barmer breed) consumed on average 1.31 kg (?DM) each daily of dried summer lopped Khejri leaves (Bohra 1980). The diet was composed only of Khejri leaves. Since the goats weighed on average 46 kg, the intake per goat ACU ( $W^{0.75}$ ) would be 5.35 kg (?DM).

3. A feeding trial with camel in W Rajasthan showed that the daily intake of Khejri leaves could be 5.7 kg (?DM)/camel ACU (derived from Mathur 1976 quoted in Bohra et al. 1980 and assuming camel weights as in Appendix 7a) (no information was quoted concerning details of the feeding trial, the season of harvest of the leaves and on whether the leaves were fed dry or fresh).

## APPENDIX 23

Chemical composition of foliage of 7 of the better fodder WPs in  
W Rajasthan (% of ?DM) (For sources and explanation see Notes below).

SPECIES	Season of Sampling	<u>% Dry Matter</u>			<u>CP</u>			<u>Phosphorus</u>			<u>Calcium</u>			
		W	S	M	W	S	M	W	S	M	W	S	M	
<u>Acacia nilotica</u>	1/				13.9			0.1				2.60		
<u>Ailanthus excelsa</u>	2/					(19.6)								
	3/		(29.6)			(16.3)			(0.17)				(1.5)	
	4/		(32.1)			(19.9)			(0.24)				(2.1)	
	5/		(27.4)			(19.8)			(0.20)				(2.0)	
<u>Albizia lebbek</u>	1/				29.2			0.2				1.80		
	2/					(16.8)								
	6/		(39.6)			(18.1)			(0.14)				(2.0)	
	7/		(44.2)			(21.1)			(0.03)				(4.3)	
	8/		(36.8)			(20.1)			(0.04)				(3.6)	
	9/					(16.8)			(0.15)				(2.6)	
<u>Prosopis cineraria</u>	1/				13.9			0.2				1.90		
	2/					(14.0)								
	10/				17.5	15.4	14.3	0.16	0.18	0.18	2.00	1.92	1.94	
	11/	44.8	40.7	34.9	16.5	14.5	15.3	0.22	0.24	0.20	2.40	2.39	2.12	
	12/					(14.2)								
	13/					14.2								
	14/					(14.1)								
<u>Salvadora oleoides</u>	1/ 15/				9.6			0.1						
<u>Salvadora persica</u>	1/				14.2			0.2				8.8		
<u>Zizyphus nummularia</u>	1/				11.7			0.2				1.6		
	16/				14.6	14.7	14.2	0.16	0.16	0.19	2.17	2.07	1.70	
	17/					(14.1)			(0.14)				(2.79)	
	18/					(10.5)			(0.40)				(3.4)	
	19/				14.3			0.14			2.43			
	20/					(13.8)			(0.30)				(2.1)	
	21/		(c.50)			(12.6)								

Notes: 1 - 21 = references, see next page.

Season: W = winter; S = summer; M = monsoon.

Other explanations, see next page.



Notes: The figures shown in brackets in the Table indicate that either the data refer to a mean value for analyses of leaves sampled in different seasons (stated below with appropriate reference) or that there was no indication of when the leaves were harvested. The State in which the leaves were harvested is mentioned in brackets after each reference. Most analyses refer to leaves alone; those which are known to have included small twigs are mentioned in brackets after the relevant reference.

Sources: 1 Ganguli et al (1964) (Rajasthan); 2 Ghosh et al (1981) (Rajasthan); 3 Bhandari et al (1972) (Rajasthan); 4 Singh et al (1977) (Rajasthan); 5 Bhandari et al (1973) (Rajasthan); 6 Sharma et al (1966) (Punjab, mean values of 7 samples through the year; the data refer to leaves and twigs as traditionally fed to livestock); 7 Khajuria (1965) (Jammu); 8 Khajuria et al (1968) (Jammu); 9 Gupta (1980) (U.P.); 10 Bhimaya et al (1964) (area where sampled not specified); 11 Gupta et al (1974b) (Rajasthan; samples included tiny twigs); 12 Bhandari et al (1979) (Rajasthan); 13 Bohra (1980) (Rajasthan); 14 Gupta (1967) (Rajasthan) (in Bohra et al 1980); 15 Mann et al (1984) (Rajasthan); 16 Kaul et al (1963) (area where sampled unspecified); 17 Nath et al (1969) (Rajasthan); 18 Singh et al (1977) (Haryana); 19 Malik et al (1970) (Rajasthan); 20 Mathur (1976) (Rajasthan) (in Bohra et al 1981); 21 Bohra et al (1981) (Rajasthan).

APPENDIX 24A

Crude Protein, dry matter intake and liveweight response in feeding trials of foliage of the better fodder WP species which occur in W Rajasthan (derived from various authors)

Species	Animal	Status of leaves (Dry=D Fresh=F)	CP	CP digest- ibility	Digest- ible CP	Dry matter digest- ibility	Dry matter intake kg/ACU (W <sup>0.75</sup> )/day	Live weight change (% of initial body weight)	Period trial (days)	Author Code (see Appendix 24B)
<u>Ailanthus excelsa</u>	Sheep	G	19.9	81.7	16.3	66.3	5.9		40	A
<u>Ailanthus excelsa</u>	Sheep	G	16.3	80.2	13.1	70.0	7.4	+1.2	28	B
<u>Albizia lebbek</u>	Sheep	G	16.8	65.0	10.9*	50.8	5.3	+2.9	30	C
<u>Albizia lebbek</u>	Cattle	?	20.1	64.5	13.0	42.4	5.2	+2.0	23	D
<u>Prosopis cineraria</u>	Sheep	D	14.2	34.8	4.9*	32.5	4.2	-0.6	28	E
<u>Prosopis cineraria</u>	Sheep	D	14.2	22.0	3.1	41.4	3.3	+1.4	17	F
<u>Prosopis cineraria</u>	Goat	D	14.2	38.9	5.5	48.8	5.4	+3.1	17	G
<u>Prosopis cineraria</u>	Camel	?	11.9	74.8	8.9*	44.7	4.5*			H
<u>Prosopis cineraria</u>	Sheep	?	14.1	7.1	1.0*	38.9				I
<u>Zizyphus nummularia</u>	Sheep	D	10.5	33.1	3.5	50.1	5.1*	none	21	J
<u>Zizyphus nummularia</u>	Goats	D	10.5	36.3	3.8	51.3	8.4*	none	21	K
<u>Zizyphus nummularia</u>	Sheep	D	14.1	38.1	5.4	45.9	3.5	-6.4	58	L
<u>Zizyphus nummularia</u>	Sheep	D	14.3	39.0	5.6*	52.6	4.1*	positive	35	M
<u>Zizyphus nummularia</u>	Camel	?	13.8	43.5	5.9*	56.8	4.4*			N
<u>Zizyphus nummularia</u>	Sheep	D	12.6	32.2	4.1	51.6	4.9*			O
<u>Zizyphus nummularia</u>	Goats	D	12.6	28.8	3.6	48.1	5.8*			P

Note: \* = indicates that the figure was not given by the authors and has been calculated. In the case of dry matter intake values, it means that some assumptions have been made concerning the liveweight of the stock (see Appendix 7A). Intake values have often been given as a percentage of body weight.

## APPENDIX 24B

Notes concerning some of the experimental details and results of feeding trials with foliage of fodder WPs which occur in W Rajasthan.

(The letter codes correspond with the coding given in Appendix 24A and Figs 9.1., 9.2. and 9.3.).

A. From Singh et al. (1977a) (area of study Rajasthan). No details were given concerning the methodology followed during the last 7 day's metabolism trial. No information given on previous feeding management. The animals were yearling rams and showed a positive balance for nitrogen, calcium and phosphorus. A trial run concurrently with dry Ailanthus excelsa leaves supplemented with molasses showed that the DCP intake from green leaves was almost double that of dry leaves mainly due to higher intake levels. The phosphorus balance was negative in animals fed with dry leaves. The season of harvest of the leaves was not mentioned.

B. From Bhandari et al. (1972) (area of study Rajasthan). The animals were confined to a metabolic cage during the last 7 days of the trial for urine and faecal collection. No information was given concerning the feeding management of the experimental animals prior to the trial. The animals were adult rams. The season of harvest of the leaves was not mentioned. The animals showed a positive balance for nitrogen, calcium and phosphorus during the trial period.

C. From Gupta (1980) (probable area of study Uttar Pradesh). No details given concerning the methodology followed during the last 7 day's metabolism trial or the previous feeding management. No details were given as to the age or sex of the animals. The balance was

slightly positive for nitrogen, positive for calcium and negative for phosphorus. The season of harvest of the leaves was not given.

D. From Khajuria et al. (1968) (area of study Jammu). No details concerning the last 5 days' collection period. The animals used were not accustomed to Albizia lebbek fodder at all (belonging to a Government Cattle Farm); the dry matter intake increase by 25% between the beginning and the end of the experiment. The animals were mature bullocks. The phosphorus intake and retention was insufficient for maintenance. The season of harvest of the leaves was not mentioned.

E. From Bhandari et al. (1979) (area of study Rajasthan). No details concerning the last 7 days' digestive trial or the previous feeding management. The animals were adult rams. The animals were "seriously deficient in both protein and energy" resulting in loss of weight. The tannic acid level of the leaves was found to be "only" 2.5% suggesting to the authors that the low digestibility of protein and dry matter was not due to this compound; some other digestion inhibiting compounds could have been present and alkaloids and lignin were suggested as possibilities. The season of harvest of the leaves was not given.

F/G. From Bohra, (1980) (area of study Rajasthan). The last 7 days' collection period was in individual metabolic stalls. No details concerning the previous feeding management. The animals were adult males. The leaves were air dried and had been harvested in the summer; the trial took place in July (monsoon). Goats (G) excreted 23% less N in the urine and faeces and retained c. 210% more N than sheep (F). Goats had a higher intake than sheep and obtained more energy per unit weight of fodder than sheep. The foliage apparently contained 11.6%

tannins (on DM basis). Sheep consumed 112% more water/kg of food intake than goats.

H. Mathur (1976) in Bohra et al. (1980) and Ghosh et al. (1981). (area of study Rajasthan). No details given concerning experimental methods followed or types of camel. The foliage was winter lopped.

I. Gupta (1967) in Bohra et al. (1980) and Ghosh et al. (1981) (area of study Rajasthan). No details given concerning experimental methods or type of sheep. The leaves had been lopped in winter. The nitrogen balance of the animals was negative. The tannin concentration of the leaves was reported to be 15% of DM.

J/K. From Singh et al. (1977) (probable area of study Haryana). No details given concerning the last 5 days' collection period, the previous feed management or the type of sheep (J) or goat (K). Both sheep and goats were in positive balance for nitrogen, calcium and phosphorus. The authors concluded that the foliage of Bordi is a satisfactory maintenance ration for non-producing adults of both livestock types. The season of harvest of the foliage was not mentioned.

L. From Nath et al. (1969) (area of study Rajasthan). The last 7 days' collection period was in metabolic stalls. Dry matter intake was measured daily and body weight weekly during the 8 weeks of the trial. The animals were "healthy and disease-free" rams of about 8 months of age. They were from the Central Sheep and Wool Research Institute flock suggesting that their previous diet might not have included much Bordi fodder. The data provided in Appendix 24A refers to the trial with the Malpura (indigenous) breed. Results showed that the Rambouillet breed was not as efficient at utilizing Bordi fodder.

Their intake was lower and their weight losses greater during the trial than pure breed Malpura of Rambouillet x Chola crosses. Intake levels dropped by c. 20% between the first and fourth week of the trial. All animals lost weight and the authors therefore concluded that the energy available from the diet was not adequate for growing ram lambs of this age. However during the last 7 days the animals showed a positive balance for nitrogen.

The authors suggested that the low intake levels may have been due to the low protein digestibility (perhaps due to digestive inhibitors) and the low phosphorus content of the fodder resulting in a negative phosphorus balance. There are also indications that the animals were starting to increase their intake towards the end of the trial. It is therefore also possible that after a longer period on Bordi forage, that the animals' digestion process might be able to improve the digestibility of the fodder thereby leading to further increases in intake and perhaps the resumption of growth. The season of harvest of the fodder was not mentioned.

M. From Malik et al. (1970) (area of study Rajasthan). The last 7 days' collection period was in metabolic stalls. The sheep were yearling ram lambs and were fed on foliage harvested in November and December. The authors recommended that Bordi fodder as sole feed does not meet the requirement of growing ram lambs since the animals showed reduced weight gains over the study period. While the nitrogen balance was positive, it was insufficient for growth. The phosphorus balance was negative. In a separate trial the authors found that summer lopped Bordi fodder was even less palatable (lower intake).

N. Mathur (1976) in Bohra et al. (1981) (area of study Rajasthan).

No details given concerning experimental methods, previous feeding management or the season of fodder collection.

O/P. Bohra et al. (1981) (area of study Rajasthan). No details were given concerning the experimental method, the previous feed management of the livestock, or the season of harvest of the fodder. The high lignin content of the foliage (11% DM) was given by the authors as a possible reason for low digestibility values and therefore of the low intake particularly in sheep (O). The nitrogen balance was positive in both sheep (O) and goats (P).

## APPENDIX 24C

Explanations concerning the dry matter digestibility of tropical  
herbaceous forage

The derived relationship (Fig. 9.3) for DMD of herbaceous forage in W Rajasthan in relation to CPC was obtained from Wilson (1982) who presented data which suggests that there is a drop in DMD of approximately 15% for each 20° change in latitude towards the equator. It is assumed that W Rajasthan lies 20° south of the temperate regions to which Minson's (1982) data in Fig. 9.3 refer.



## APPENDIX 25

Calculation to obtain the average CP value of dry season fodder  
available from private cultivated land.

The average CP value of fodder during a normal rainfall year from private cultivated land on a 10 ha farm given that the legume residues amount to 2.16 tonnes (DM) and have an average CP content of 10.5%, the millet staw residue and the pasture amount to 1.36 tonnes (DM) and have a CP content of 3.1%, and the Khejri forage amounts to 2.14 tonnes (DM) and has a CP content equivalent to 9% in herbaceous forages, is as follows:

$$\frac{[(2.16 \times 10.5) + (1.36 \times 3.1) + (2.14 \times 9)]}{5.66} = 8.15\% \text{ CP}$$

The average CP value of fodder from the same farm during a moderate drought year, assuming the same CP levels as for a normal rainfall year and data on yields from Tables 9.3 and 9.4, is as follows:

$$\frac{[(0.8 \times 10.5) + (0.74 \times 3.1) + (2.14 \times 9)]}{3.68} = 8.14\% \text{ CP}$$

## APPENDIX 26

Assumptions and calculations to obtain the average number of ACUs owned by 10 ha holdings in Jodhpur and Nagaur districts.

A. Derived from Bose et al. (1966). Table A.26.1 gives the average number of different types of livestock which were owned in 1961-62 by holdings which ranged in size from 6.7 to 13.4 ha. The numbers are converted to ACUs ( $W^{0.75}$ ) using the same assumptions and conversion factors which were used in Appendix 7A.

Table A.26.1. Average livestock numbers for holdings in the 6.7 to 13.4 ha size category (from Bose et al. 1966) and equivalent ACUs ( $W^{0.75}$ ).

Livestock type	Numbers	ACU conversion factor	ACU numbers
Bullock	1.88	1.0	1.88
Cow	2.45	1.0	2.45
Young cow	1.59	0.59	0.94
Buffalo	0.71	1.0	0.71
Young buffalo	0.38	0.59	0.22
Camel	0.37	Y: 0.12 x 0.75	0.09
		A: 0.25 x 1.27	0.32
Sheep	4.16	Y: 1.4 x 0.12	0.17
		A: 2.8 x 0.20	0.56
Goat	4.02	Y: 1.3 x 0.12	0.16
		A: 2.7 x 0.20	0.54
Total			8.04

B. Jodha (1980) provided some data on the number of 'Animal Units' (see Appendix 7A) per household in a number of sample farms from Jodhpur and Nagaur districts in 1964-1965. Table A.26.B gives this data and conversions to Animal Units which would be expected on farms of 10 ha size assuming a linear positive relationship between size of the farm and Animal Units (this appears to be a realistic assumption over the size difference which we are dealing with, according to Bose et al's 1966 data). The Table also converts the 'Livestock Units' to ACUs ( $W^{0.75}$ ) using the ratio between total 'Animal Units' and total 'ACUs  $W^{0.75}$ ', for 1961 in Appendix 7A.

Table A.26.B. 'Livestock Units' on farms in Jodhpur and Nagaur districts converted to 'Livestock Units' and ACUs ( $W^{0.75}$ ) for 10 ha units.

	Area of	Animal	Animal Units	ACU ( $W^{0.75}$ )
District	holding (ha)	Units	/10 ha farm	/10 ha farm
Jodhpur	23	18	7.8	6.9
Nagaur	18	17	9.4	8.3

ANNEXE I

"The Role of Silvopastoralism in Small  
Farming Systems"

In: "Agroforestry Systems for Small-  
Scale Farmers" (D.A. Hoekstra  
et al., eds.), 1983, pp. 147-  
169. ICRAF/BAT, Nairobi.

## THE ROLE OF SILVOPASTORALISM IN SMALL FARMING SYSTEMS

*Patrick Robinson\**

1. *Introduction*

Silvopastoralism implies a management system in which there is an attempt to integrate the production of woody perennials with livestock husbandry in such a way that more benefits are obtained than by either tree or animal production alone.

Based on some results from research in various fields of agriculture and forestry, this paper attempts to outline the kinds of benefits which may be potentially achieved in small farming systems through development of silvopastoralism. This paper concentrates discussion on those small farming systems in which the main-stay of production is obtained from annual crops; in which there is at least one dry season; and part of whose area, which can be private, tribal or communal land, is permanently or cyclically unsuitable for crops. Such farming systems are not uncommon in many tobacco-growing areas in Africa.

Several preparatory stages are required in order to come up with a design for research and extension workers in the field which would aim at maximising sustainable production in such systems. These are:

1. the identification of factors which limit production and profitability;
2. the evaluation from existing research results and from operational systems elsewhere of the range of possible alternative ways of improving production in the various components of the farming systems concerned;

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3. the selection out of the range of possibilities identified above of the improvements which are likely to be most suitable and feasible given the location-specific constraints identified, the resources available, and the existing and anticipated socio-economic situation.

Initially it is necessary to outline the kinds of roles which livestock can directly or indirectly play within such farming systems.

2. *Direct roles of livestock in small farming systems*

Table 1 provides a list of the various roles which livestock perform in different systems.

Table 1 : Direct roles of livestock in small farming systems

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<i>Animal products for home consumption</i>
<i>Food: milk, blood, meat</i>
<i>Non-food: wool, hair, hides, bones</i>
<i>Power</i>
Threshing, lifting of water, transport, ploughing
<i>Source of income or barter</i>
<i>Income: milk, live young for rearing, stock for slaughter, non-food products</i>
<i>Investment</i>
<i>Insurance/storing wealth</i>
<i>Social functions</i>

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*Animal products for home consumption.* There is a shortage of food, particularly protein, in many of the situations we are concerned with and this can be particularly acute at certain times of the year; these shortages can be partly alleviated by the various food products obtained from animals (Roth and Norman 1978). The relative importance of these products to human nutrition depends on the quantity available and also

on the timing of their availability in relation to other foods (unless appropriate techniques are used to process the raw product into a non-perishable good, which is seldom done).

*Power.* The provision of animal power is important in saving human energy and in raising labour productivity. The time of year when this power is most needed often does not coincide with that when the animals are in best condition and performing best (e.g. for lifting water, ploughing, and sometimes for transport).

*Sources of income or barter.* The role of animal products in providing purchasing power (by cash or barter) can be particularly important. However, the particular type and timing of requirements (e.g. income, investment, savings, insurance) place different levels of priority on the different types of production parameters and their timing. For income generation, the timing of sale is important in relation to possible cash flow problems (e.g. pre-harvest period, school fees); in such situations the most appropriate animal production system may be that which provides the products at those specific times. The value of such products may be further increased where better sale prices prevail during these periods. Alternatively it may be that regular income is desirable, in which case milk production is particularly appropriate where a nearby market exists.

For "investment" purposes, the most appropriate type of production would be one where the greatest returns are obtained from the minimum amount of "tied up" capital, assuming risk is not increased. In this case, better birth rates and increased growth rates are desirable production parameters.

For "insurance" or the "storage of wealth", priority is usually given to increasing the number of stock, although better quality and/or more valuable livestock may be desired where risk is not increased (e.g. more disease-susceptible and improved breeds).

*Social functions.* Livestock also play important social functions in many communities (e.g. status). Often this is translated into requirements for more and/or "better" livestock. However, the perception of quality may not coincide with production qualities (e.g. the size of horn or coat colour patterns may determine quality irrespective of production qualities).

Hence different farming systems have different orders of preference for livestock functions depending on perceived farming problems and potentials, and on social functions. Different communities translate this by placing different values on various parameters of "production" and the timing of such "production".

It seems clear that, except for frequent cases of the social function, the primary objectives of animal production do not have to include the maximum expansion of herd size, except perhaps for minimizing risk in the event of poor years leading to the death of significant numbers of stock. On the contrary, given appropriate control of the grazing resources, the objectives would seem to be best satisfied by the maintenance of a herd size commensurate with the fodder resources available during the dry part of the year, at the same time providing as much of the relevant animal production types as possible. The parameters involved (many are interrelated) may be maximum off-take (milk or stock per number of individuals kept for breeding (i.e. good breeding rates, low mortalities, early reproductive maturity, long reproductive life); hence the need for minimum breeding replacement stock, good growth rates and long working life (for draught animals).

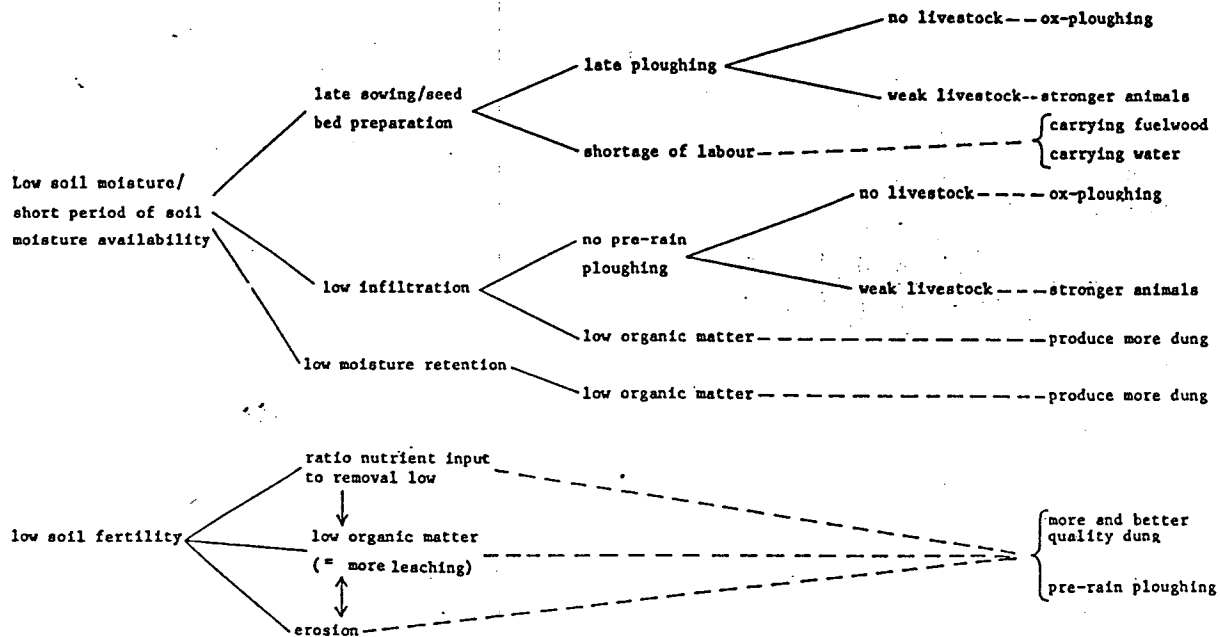
### 3. *The indirect role of livestock in sustaining or improving crop production*

Table 2 shows in a step-wise manner (columns A + B + C) how livestock can help improve crop production through indirect influences on soil fertility and soil moisture regimes.



Table 2: Indirect role of livestock in improving crop production

(A) Direct reason for low/ variable crop production	(B) Indirect reason (about which something something can be done)	(C) What role can livestock play in indirectly improving crop production
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—————> indicates interaction and direction of influence.

Both the quality and the quantity of the manure input to the cropping system are important. Dung quality is determined by the quality of the feed since ruminants excrete 60% to 90% of the major nutrients (N,P,K) they consume (Roth and Norman 1978).

Ploughing helps to overcome the frequent problems of labour shortage which occur at planting when hand-hoeing is practised, and therefore helps improve production especially as ideal weather conditions for planting can be taken advantage of (e.g. tobacco) (Levy and Havinden 1982). The role of pre-rain ploughing in improving soil conditions for plant growth and in enabling timely seed bed preparation and planting to benefit from the first rains must also be emphasized. Hence availability of effective plough teams prior to the rains would seem to be an important prerequisite to successful crop farming systems. Since the quality and quantity of available pre-rain fodder is usually poor, improvements in the nutrition of plough animals would help to improve crop production.

#### 4. *Livestock performance*

Indigenous breeds of livestock are usually well adapted to local environments. They are often reasonably tolerant to heat, to seasonally poor nutrition levels and even in some cases to certain diseases, e.g. Trypanosomiasis (ILCA 1979). However, their production performance is poor. Table 3 compares various aspects of cattle productivity derived from studies carried out in West Africa (quoted in Roth and Norman 1978, Kowal and Kassat 1978) with what are considered reasonable estimates of productivity for temperate grazing systems.

The reasons for such poor performance are the low production potential (genetic) of breeds, seasonally poor nutrition, environmental (heat stress) and health (diseases) problems and the frequent demands on the stock to perform multiple functions as a result of which the productive efficiency of each role is reduced.

Table 3 : Comparison of cattle performance in West Africa and temperate grazing systems

	West African studies	Temperate grazing systems
Liveweight gains	1/3	1
Milk production/year/cow	70 kg	2700 kg
Mortalities		
Calves	20% - 50%	10%
Adults	5% - 20%	5%
Calving rate (of breeding females)	50% - 60%	80% - 90%
Onset of reproductive maturity	3 - 6 years	1½ - 2 years

##### 5. *The integration of woody perennials and the livestock component*

Two objectives merit an increasing amount of attention with regard to the small farming systems with which we are concerned, namely, the growing of fuelwood and the improvement of animal performance in each of the desired functions. The introduction of woody perennials into the system in such a way that animal production and performance are not only unimpaired but potentially increased is highly desirable. The production response of indigenous (unimproved) livestock to both improved nutrition and to an improved climate is lower than that of crossbred stock. Hence the degree to which the climate and/or nutrition can be improved determines the extent to which improved breeds can productively be introduced and specialization can take place in terms of the roles of livestock in the farming system.

Therefore, by examining the way in which trees have a negative or positive effect on animal nutrition and the animal's climate and health, and how they grow in association with pasture and animals, one can determine whether the integration of trees and livestock production is desirable. If it is considered desirable, the management of the various components should be considered together with the extent to which it may be possible to introduce improved livestock breeds.

#### 5.1. *The role of trees in animal nutrition*

Trees can influence animal nutrition either directly through their own fodder (leaves or pods/fruits) or through effects on the underlying pasture.

5.1.1 *Direct influence.* Table 4 provides data on the crude protein and fibre content of common sources of fodder in different parts of Africa. The data indicate the possibility for browse to act as a protein-rich supplement to the coarser grasses and crop residues. Figure 1 indicates how the inclusion of *Prosopis juliflora* pods up to a certain level in the diet can increase the digestibility of the oat/hay roughage component. Important factors in the value of browse, either on its own or as a supplement to other forage, include the timing of the leafy period and monthly fluctuations in leaf fodder quality in relation to fodder needs. While some tree species e.g. *Prosopis cineraria* (Table 5) show little fluctuation in leaf nutrient quality over the year, others (e.g. *Dendrocalamus hamiltonii* Figure 3 in Himachal Pradesh India) show considerable seasonal differences in nutrient content and quality. The content and seasonal fluctuations of digestive inhibitors in the leaves should also be considered when evaluating fodder quality: *Quercus incana*, for instance, (Himachal Pradesh: Figure 2) shows fluctuations in leaf tannin concentrations, which may have considerable effects on digestibility. Yet other species while providing good quality fodder when ingested in moderate quantities, become toxic above certain levels of intake (e.g. *Leucaena leucocephala*).

Table 4: Chemical composition of common sources of fodder.

<i>Source</i>	<i>Crude protein %</i>	<i>Fiber %</i>
Maize stover	5.0 - 6.0	35.0 - 40.0
Sorghum stover	4.5 - 5.0	35.0 - 40.0
Annual grasses (Dry P.) (Sudano-Sahelian Z)	2.5 - 3.0	35.0 - 45.0
Perennial grasses (Dry P.) (Sudano-Sahelian Z)	3.5 - 4.0	35.0 - 40.0
Grasses (Yearly X) (Ghana-Interior Savanna)	3.5 - 4.5	30.0 - 40.0
<i>Browse</i>		
East Africa (X)	13.0 - 14.0	25.0 - 30.0
West Africa (X)	12.0 - 13.0	15.0 - 20.0
Legumes E.A. (X)	14.0 - 15.0	25.0 - 30.0
Legumes W.A. (X)	16.0 - 17.0	20.0 - 25.0
Ghana (Int. Sav.)	14.0 - 15.0	18.0 - 22.0

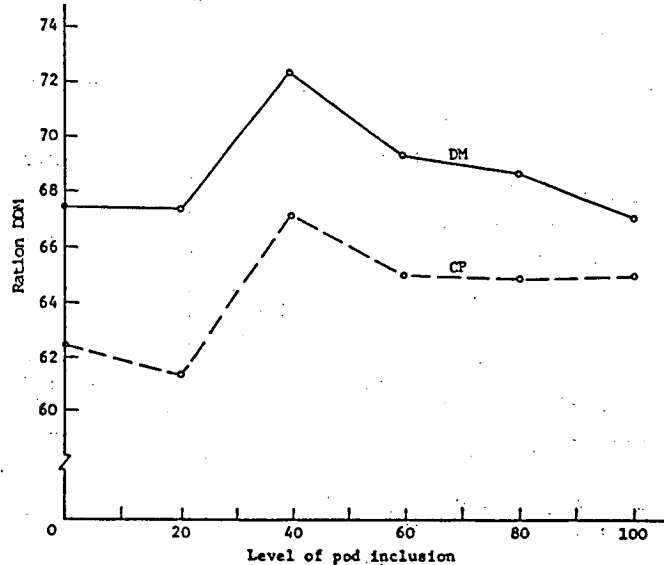
Source : Compiled by F. Torres (1981).

Table 5: Effect of season on the nutrient contents of *Prosopis cineararia* (on DM basis)

SEASON	CP	CF	NPE
Summer	15.28 ± 0.2	11.1 ± 0.2	66.1 ± 0.3
Autumn	15.68 ± 0.6	12.2 ± 0.4	62.0 ± 1.1
Winter	16.00 ± 0.3	14.2 ± 0.1	52.9 ± 1.5
Spring	14.70 ± 0.5	15.1 ± 0.3	46.2 ± 1.1

Source: Gupta, M.L. and C.S. Mathur, 1974

Figure 1: Effects of *Prosopis* pods supplementation upon digestibility of an oat-hay roughage.

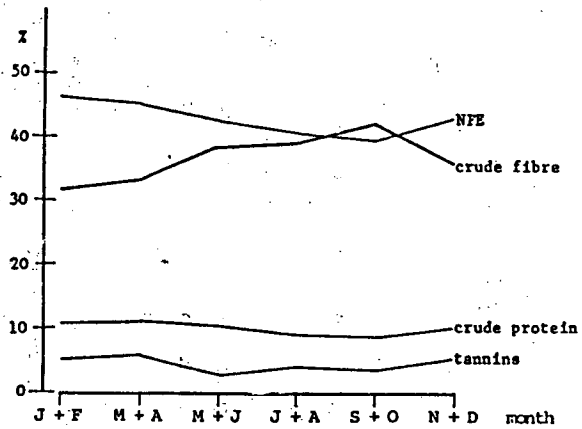


Source: Kargaard, J & F.J. van der Herwe, 1976.

Figure 2(a): *Quercus incana* (Bon): Seasonal variation of dry matter content in fresh leaves



Figure 2(b): *Quercus incana* (Bon): seasonal variation in the chemical composition of dry matter leaves



NFE = Nitrogen free extract.

Figure 3(a): *Dendrocalamus hamiltonii* (Maggar): seasonal variation of dry matter content in fresh leaves

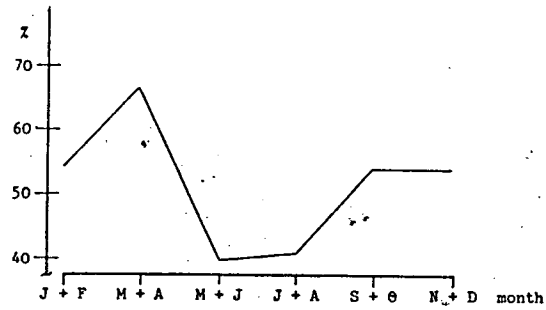
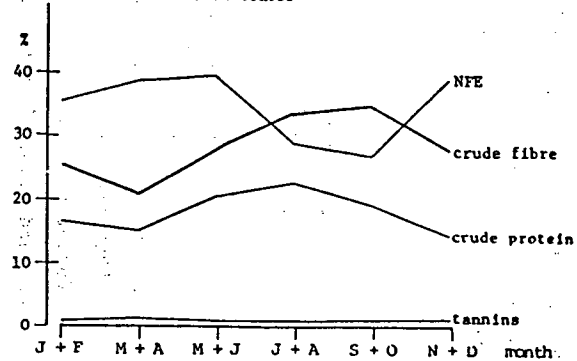


Figure 3(b): *Dendrocalamus hamiltonii* (Maggar): seasonal variation in the chemical composition of dry matter in leaves



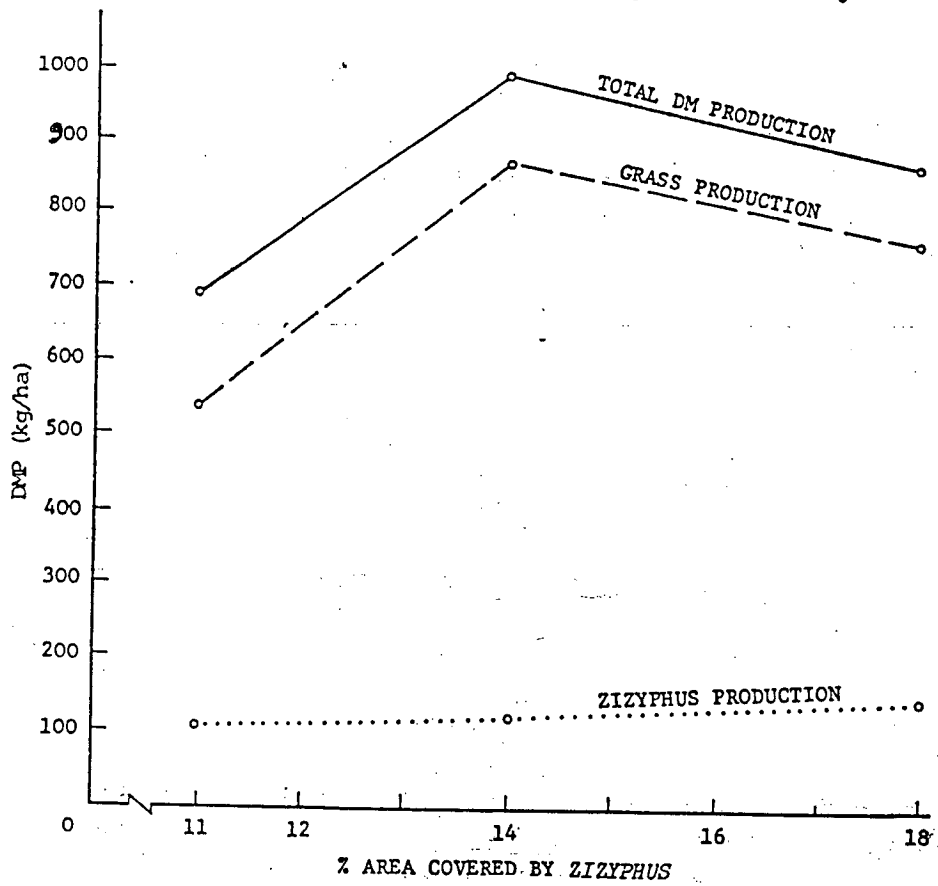
5.1.2 *Indirect influences.* Woody components can have an indirect influence on animal nutrition in several ways. The *total pasture production* can be increased in the presence of a certain density of trees, e.g. with low densities of *Zizyphus* in arid zones of India (Figure 4). However, other species (e.g. *Acacia aneura*) in semi-arid Australia have a considerably detrimental effect on total pasture production even at very low densities (Figure 5).

The *quality* of the pasture may be influenced. There is evidence that the often poor competitive ability of legumes in the tropics and sub-tropics against grasses is improved with a certain degree of shading (Ludlow *et al.* 1974 for Australia, Goldson 1973 for Coastal Kenya). Some shade may therefore be one way of helping to maintain a suitable grass-legume balance, a balance which is difficult to establish (Whiteman 1980) but desirable since shortages of nitrogen are a major limiting factor to productivity in most tropical and sub-tropical areas (Wong and Wilson 1980) including semi-arid regions (Félker and Clark 1980). The digestibility of grasses is inversely proportional to their stage of maturity; hence any environmental factor (e.g. reduced light and/or temperature) which reduces their growth rate and particularly delays the onset of flowering is likely to be beneficial to pasture quality (Whiteman 1980).

Some evidence also suggests that the onset of pasture growth can occur earlier in the understory of trees (e.g. with cashew trees on the Kenya Coast: Goldson 1973), which may be due to better moisture conditions at an earlier stage in the growing season. Alternatively, more perennials are often found in the understory compared to open pasture and perennials have an advantage over annuals at the start of the growing season (e.g. Goldson 1973); further pasture growth can continue for sometimes considerably longer, (e.g. up to 3 months on the Kenya Coast) into the dry season, mainly owing to a suitable moisture regime being maintained for longer (Goldson 1973, Kennard and Walker 1973 in Zimbabwe).

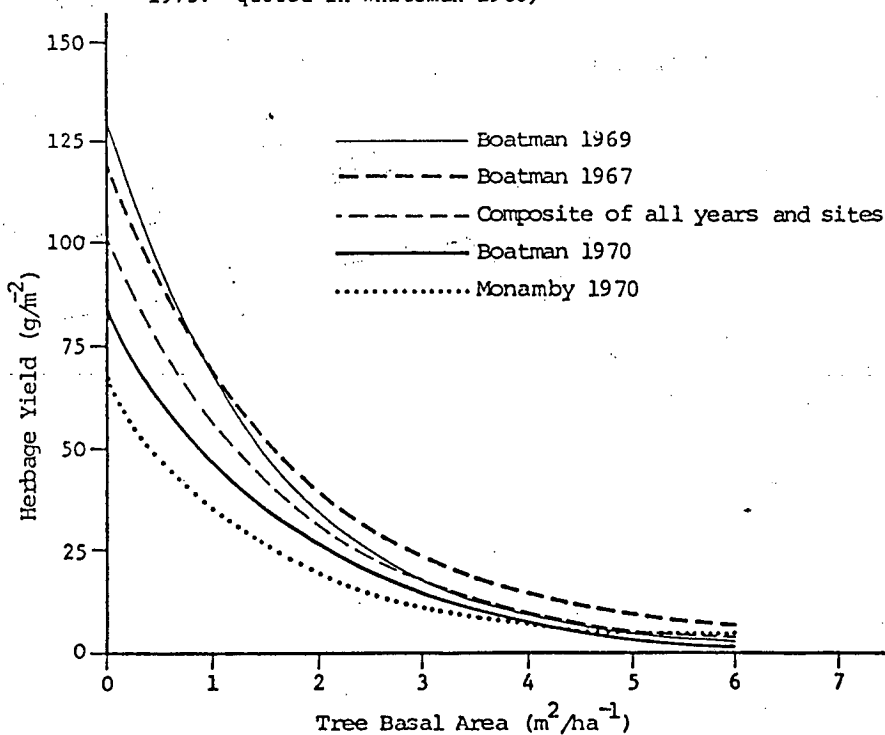


Figure 4: Effect of Zizyphus density on fodder production/ha (kg)



Source: Kaul, R.N. 1963.

Figure 5: Relation between herbage yield ( $\text{g}/\text{m}^2$ ) and tree basal area ( $\text{m}^2/\text{ha}$ ) of *Acacia aneura* in semi-arid Australia. (Beale 1973: quoted in Whiteman 1980)

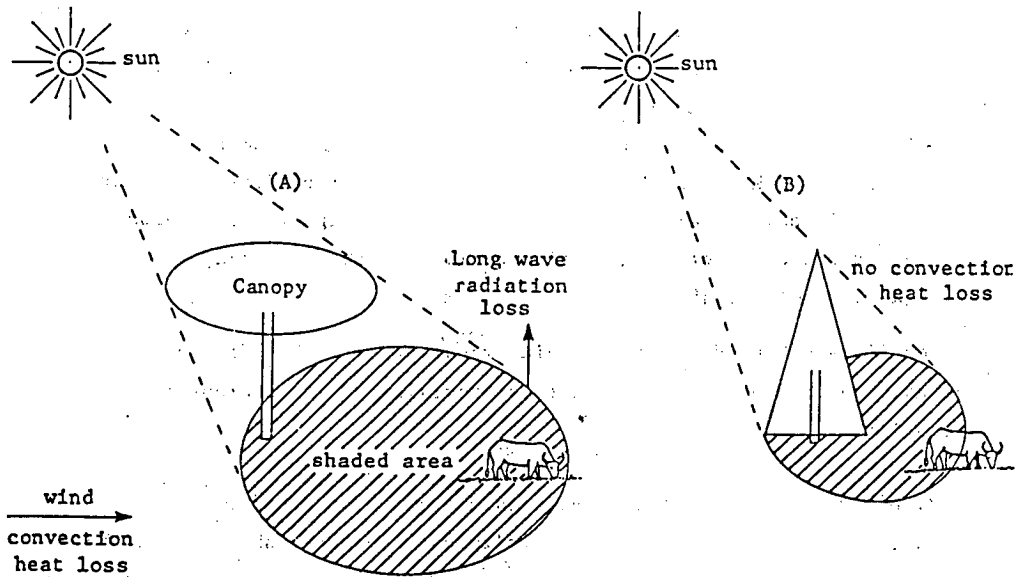


The factors which affect the indirect influences are numerous and are likely to vary considerably qualitatively and quantitatively according to the specific site conditions (climate, soil type, rooting depth, water table, etc), and according to the tree and pasture species concerned (e.g. their rooting and canopy characteristics, their density). The influence of the trees on the site conditions is also likely to be specific in time and place (e.g. in relation to moisture and nutrient effects). The indirect effects on animal nutrition which are mediated through the energy balance of livestock are discussed in the next section.

### 5.2. Trees and heat stress alleviation

The main processes by which heat exchange between animals and the environment take place are short wave radiation (mainly input), long wave radiation (mainly output), and convection. Trees with characteristics of shape A (Figure 6) minimize short wave radiation input, enable long wave radiation losses (cattle have been shown to behaviourally respond positively to shades enabling long wave radiation losses: Kelly *et al.* 1957), and allow wind through enabling convection heat losses. Shade B does not allow much short wave input reduction, and reductions in wind speeds at animal height may raise the air temperature at that level.

Figure 6: The role of tree shape in heat stress alleviation



The direct and indirect effects of heat stress reduction by trees on animal production are numerous, and the extent of the effects depends on the climate and the animal breed. We shall enumerate but a few.

1. Animals eat and graze for longer.
2. Animals need less water (20% less in the case of a Jersey milk herd on the Kenya Coast: Goldson 1973).
3. The conversion efficiency of fodder should be improved (Preston and Willis 1974).
4. Growth rates, milk yields and wool production are improved (independently of the quality and quantity of fodder available: (Kasjanov 1965, McIlvain and Shoop 1971, Hopkins *et al.* 1980).
5. The reproductive rates should be improved (independently of quality and quantity of fodder available) due to the following likely influences: earlier puberty (related to higher growth rates), higher conception rates, more regular fertile periods, lengthened reproductive life, reduced embryo loss and need for a lower ratio of males to females (Hafez 1968, Terrill 1972, Webster and Wilson 1980).
6. The survival rate of the offspring is also higher due to the following likely influences: mothers in better condition, easier parturition, larger and stronger offspring, higher milk yields and therefore shorter sensitive period for the offspring (Hopkins *et al.* 1980).

Hence livestock production per unit amount of available forage should be able to increase given shade tree provision at the appropriate locations.

### 5.3. *Disease and health considerations and silvopastoralism*

Shade, by helping to improve the health of livestock, should contribute towards greater disease resistance. However, stock concentrations at any site may promote the build-up of parasites, particularly if the shade is close to water. If the trees are located in an area protected from the wind, the concentration of head flies and other air-borne insects may be detrimental to the well-being and production of stock.

The special problem of Trypanosomiasis has to be considered. Trees and shrubs, particularly those with canopies reaching close to the ground (Challier pers comm.), do promote tsetse infestations (Turner 1981). Certainly some tobacco-growing areas do suffer from tsetse incidence to such an extent that the ploughing has to be done by tractor (e.g. in the Meru area in Kenya).

5.4. *The production of the tree component in low-density stands*

In most situations, planted trees are expected to have a productive rather than a purely service role. In an integrated pasture/livestock/tree system, an important factor to be considered is the rate at which the production from the tree component decreases with decreasing tree densities. Table 6 shows how, with appropriate silvicultural interventions, the reduction of stand density from that normally used in conventional forestry (treatment 1) to one which enables pasture to grow (treatment 6) does not necessarily entail any reduction in wood yield over the whole rotation. The tree density tree production relationship will again depend on the specific site conditions and the tree species concerned.

5.5. *Practical considerations for the silvopastoral component of small farming systems.*

This is a most complex issue due to the many ways in which production and management aspects of the livestock, pasture, tree and human component of the system interact.

The choice of tree species to be introduced in the system, their location within the farm system (on common rangeland, private pasture, field boundaries, within crop fields, in proximity to water courses, etc.) and their management (planting, watering, protection, training, shaping, pruning, lopping, coppicing, pollarding, age and size distribution, etc.) depend on numerous factors. We shall list but a few: the main roles which the trees are expected to play within the silvopastoral context (e.g. fodder, fuelwood, shade; for fodder one may

Table 6: Comparison of *Pinus radiata* yield data, Treatments 1 and 6, Mungalup experiment - W. Australia.

Age	Treatment 1		Treatment 6			
	spha	Yield ( $m^3 ha^{-1}$ ) Pulp      Saw	spha	Yield ( $m^3 ha^{-1}$ ) Pulp      Saw		
8.2	1108	-      -	500	76.6      -		
12.6	1108	-      -	250	133.1      -		
19.6	500	114.5      59.3	125	18.0      196.4		
Standing volume at age 20.5 years ( $m^3 ha^{-1}$ )			110.0	429.3	17.5	304.0
Total volume produced ( $m^3 ha^{-1}$ )			224.5	488.6	245.2	500.4

Source : F.H. McKinnell, 1979.

need a variety of species so as to reduce the toxic effects which any one species may have if fed in too high concentrations); the time when the tree functions (production or service) are likely to be most important (e.g. for fodder, one may need a variety of species so that nutritious and digestible fodder is available at the appropriate times of year; for shade, the suitable tree needs to be located where animals are kept/grazed during the most sensitive periods in terms of heat stress; the types and numbers of livestock; the seasonal differences in grazing management of livestock (e.g. tethered, herded, loose); the reproduction management of the livestock (e.g. planned or haphazard timing of reproduction and parturition); the roles of the livestock components within the system (e.g. milk production, meat production, ploughing); the production opportunity costs (e.g. likely impact of trees on crops or pasture); pest considerations (e.g. suitable micro habitat for tsetse breeding at the time of year when livestock would graze such sites, or trypanosomiasis tolerance of livestock); labour availability (e.g. zero grazing requiring cut and carry, or on-site grazing requiring lopping to make leaves available, or a browsing system); land availability for different purposes; the desirability for tree fallows on cropland; land tenure of different components of the farm system and degree of social cooperation for the management of the resources which impinge on the farm production; flexibility in terms of grazing management (e.g. availability of alternative grazing resources in order to allow tree planting within pastures).

#### 6. *Conclusion*

It seems as if there is considerable potential for some tree-animal husbandry integration in small farming systems. However, for any silvopastoral component to achieve anywhere near its theoretical potential within the overall farming system, the following conditions, among others, have to be satisfied:

1. a good understanding of the various interrelationships which are

likely to be specific in terms of the species, the site and the socio-economic situations;

2. effective research in the appropriate fields;
3. effective extension work and diffusion of information;
4. possibility for management of a complicated system;
5. some degree of control over all the resources which lead to the appropriate integration of trees, livestock and crop production (particularly important in relation to grazing management);
6. flexibility in management when a whole range of circumstances change (e.g. climate fluctuations, internal family labour fluctuations).

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## ANNEXE II

"Trees as Fodder Crops"

In: "Attributes of Trees as Crop  
Plants" (M.G.R. Cannell et al.,  
eds.), Institute of Terrestrial  
Ecology, Huntingdon, UK (In.  
Press) (29 pp).

T R E E S   A S   F O D D E R   C R O P S

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- I      Introduction
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- In: "Attributes of Trees as Crop Plants" (M.G.R. Cannell,  
J.E. Jackson and J.C. Gordon, eds.) Institute of Terrestrial  
Ecology, Huntingdon, United Kingdom. (In Press).

## 1. INTRODUCTION

When looking at the history of natural sciences and of agriculture, it is not unusual to find that certain topics have been the subject of keen interest and even investigation for certain periods, then forgotten only to be revived decades or centuries later: fodder as a product from trees is one of these topics. The current revival of interest in fodder trees is associated with the increasing emphasis placed by many individuals and institutions, who are concerned with research and development in rural areas, on the role of multipurpose trees and of agroforestry in sustainable rural development (Lundgren and Raintree 1983). The following factors have led to a renewed interest in the potential role of trees and shrubs in supplying fodder:- the seasonal shortage of pasture forage, its frequent low quality, the direct and indirect importance of livestock in most farming systems of the developing world, plus the fact that livestock have in some areas been relying successfully on woody perennials for many years for at least part of their fodder (Robinson 1983, Torres 1983).

This paper aims to look at the past reliance on fodder from woody perennials (from now on referred to as fodder trees) and at their potential in different farming systems. While the term "crop" usually implies that the plant has been planted/cultivated, the degree to which man has promoted the presence of fodder trees and consciously managed trees for fodder is often undetermined; further since in many farming systems, the reliance is to a large extent on the natural presence of trees, whether by browsing or lopping, the discussion includes fodder trees from natural vegetation. Only leaves (including shoots and twigs), fruit and pods are included here as fodder (bark and flowers may at times be important). Fodder tree - animal interactions refer to domestic stock and to game only when the latter is of direct relevance to the farming system. The role of fodder as a by-product of commercial forestry (Keays, 1971, 1975; Young, 1976) or of tree crop farming (Hutagalung 1981) is excluded where processing is required outside the farm, or where the management (if any) of the tree component is not within the farming system concerned (Nelson et al. 1984).

## II. HISTORICAL PERSPECTIVE

### A. PREHISTORICAL EVIDENCE

There is no doubt that in many parts of the world fodder trees have played an important and at times crucial role in rural communities since the earliest developments of animal husbandry. Although controversial, the earliest evidence for man's reliance on tree fodder is from Western and Northern Europe and is dated at c. 3000 B.C. or even earlier (Simmons and Dumbleby, 1974). Paleobotanic evidence, combined with the likelihood that as Neolithic man spread rapidly through Northern and Western Europe there was at first no pasture because of the abundance of trees, suggests that foliage from shredded, lopped or pollarded elms and probably other species (eg. lime, ash, holly, ivy) may have been the mainstay of most livestock throughout the year (Heybroek, 1963; Linnard, 1982; Rackham, 1980; Troel Smith, 1960).

## B. HISTORICAL EVIDENCE

### 1. Classical Times

In ancient China and India various species and varieties of Zizyphus which have fodder as one of their important products (eg. Zizyphus nummularia Burm.f.), have been used and grown for the last 4000 years (Mann, 1981). Prosopis cineraria Macbride and Zizyphus spp. are mentioned in ancient Indian scriptures, the latter not later than 1000 B.C. (Shanker, 1980; Khoshoo and Singh, 1963).

From the Mediterranean region, references to fodder trees are numerous from at least the second century B.C.. However, Amphilochous (an Athenian writer), at an even earlier date, apparently devoted a whole volume to alfalfa and "cytismus" (Medicago arborea) (Pliny, c. A.D. 23-79 - the original sadly seems to have been lost). Medicago arborea seems to have originated in the Cyclades and was introduced to mainland Greece where it is said to have led to a great increase in cheese production. It provided a yearly economic return per ha equivalent to about 1870 agricultural worker's daily wages even on moderate soil - an indication of the high fodder value to labour cost ratio of the day.

Problems of livestock feeding were acute in Roman antiquity particularly in cropland areas (White, 1970). The dependence of annual and tree crop agriculture on livestock for manure and power meant that some livestock had to remain on the farms the whole year. The shortage of grazing area (which became more acute as more land came under the plough) combined with the short pasture growing season (April to mid-June) resulted in year-round stall feeding in some areas. Hay was often harvested and various forages grown for fresh consumption or for storage as summer, autumn and winter feed (including even a root crop - turnip, particularly in Gaul). Nevertheless the agricultural husbandry writers of the day (eg. Cato, B.C. 234-149; Columella, A.D. 64 a and b; Pliny, A.D. 23-79; Varro, B.C. 36) indicate both the degree to which cropping systems depended on tree fodder and also the extent to which the choice of trees and their management took fodder production into account.

Species were ranked according to quality of foliage (whether green or dry) and of mast (fruit or seed fed fresh or dried with a subsequent soaking). Daily rations for various livestock were provided which, for different times of year, included the leaves and mast of different species either alone (leaves) or mixed with agricultural residues; it seems clear that sometimes tree leaves were the only feed available. Elm, poplar, ash and Medicago arborea (introduced to Italy between Cato and Varro's times) were planted specifically for fodder both along field boundaries and roads, and in combination with other crops (nursery techniques are even described). Although not the ideal species for supporting vines, elm was chosen for this purpose in parts of Italy because of its feed value;

NOTE 1      Actually 2000 sesterces per iugerum. Assuming 1 iugerum = 0.267 ha., and 4 sesterces being a labourer's daily wage.

NOTE 2      The specific scientific name is not given since the identity of the species is uncertain.

the "Atinian" variety of elm was preferred by some because of its more luxuriant leaf growth and better palatability even though the "Italian" variety, casting less shade, was more than suitable for the vines. The trees (and vines) were planted at 6 m spacing but on good soils, a 12 m spacing was used if an intercrop of cereals was planted. Medicago arborea which took 3 years from planting to harvesting was intercropped successfully with garlic and onions as catchcrops. The advantages of Medicago arborea were its ease of management and modest site requirements; livestock weight gains were good even when it was provided as the sole feed; it remained green for eight months of the year and the quantity and quality of ewe's milk was improved.

Further indicators of the importance and high value placed on tree fodder in Roman times include the special name (frondator) which was given to labourers who specialized in leaf stripping and lopping; such a man was able to harvest four days' worth of ox rations (equivalent to 15 kgs of hay per day) in a day. Some natural woodlands whether private or communal had regulations concerning their management and in some areas their principal value was as a source of mast mainly for pigs. Hence their name silvae glandiferae (Devèze, 1961). It was already known that the mast of different species influenced the quality of pig meat.

## 2. Middle Ages to Mid 19th Century

Little specific information appears to be available concerning fodder trees for more than a millenium after Roman times. References are mainly to fees for legal use and fines imposed for illegal use of the forest (eg. pasturage, pannage and the lopping of the tree foliage) (reviewed by eg. Linnard, 1982; Rackham, 1980 and Young, 1982 for U.K.; Devèze, 1961 for France). However, the importance of pannage is referred to frequently throughout the middle ages since the financial returns from pannage rentals were often greater than those obtained from wood products. Although the autumn carrying capacity seems to have averaged c. 1.25 to 2.5 pigs per ha of natural woodland in England, there could be a 100-fold variation in mast production between years, reflected in the yearly pannage fees received (Rackham, 1980). Devèze (1961) reports a lower price paid for pigs which had been fattened on acorns as against grain on account of the difference in meat quality, while Plaisance (1979) states that ham from pigs fattened on acorn was renowned for its good quality.

In U.K., before the introduction of improved pasture plants and of liming, and before the increased use of root crops and the enclosure of the commons (spanning the 16th and 17th Century), winter feed was often desperately short (1 beast in 5 died each winter on Scottish farms even in the 18th Century). This resulted in a considerable reliance on palatable evergreen trees and shrubs such as heather (Calluna vulgaris), gorse (Ulex europaeus) and holly (Ilex aquifolium). Both gorse and holly were planted and managed for sheep, cattle and horse fodder (Radley, 1961; Spray, 1981). Holly pollarding rights and ownership could be private or communal; stands of holly within common land often belonged to the Lord who let the trees on a yearly or longterm basis. The high rentals sometimes paid give some indication of its value. The practice seems to have been more prevalent and to have lasted longer in areas where winter feed was scarce and which suffered from very little early bite (e.g. particularly on acid sites at an altitude from 120 m to 430 m). There is



also interesting evidence that small holdings had a higher proportion of holly in their hedgerows than larger farms. Stahl in Austria wrote an early treatise on fodder trees in 1765 while Elly (1846), and Burke (1846) for Ireland and Scotland respectively, provide probably the first (and still, to date, two of the few) economic evaluations of a cultivated fodder shrub (gorse), comparing it favourably to more conventional sources of fodder. Elly (1846) includes further information on techniques and economics of establishment, yields, livestock requirements, seasonal variation in feed quality, harvesting labour requirements, and processing technology (chaffing/crushing). It was often sown on poor land and because indigenous gorse was not thought to be as good or luxuriant as the French gorse, germplasm was introduced from France to both Ireland and Scotland (Elly, 1846; Fenton 1976). Elly also mentions two important aspects which are still often neglected in fodder tree evaluations. Firstly, initial palatability is no indication of potential palatability: "Those not used to it will at first refuse, but after a little starving will prefer it to any other food". Secondly, the feed quality is maintained by frequent cuttings in evergreens.

### 3. 1850's to 1950's

More detailed studies on fodder trees, based on experience in the mountainous areas of Europe, appeared in the late 19th century and early part of the 20th century (e.g. for Austria, Wessely, 1877; Germany, Pässler, 1891, 1893; Italy, Anon, 1876; Switzerland, Brockman-Jerosch, 1936 and Grossman, 1923). The practice of tree leaf harvesting, prevalent throughout the area prior to c. 1800 died out in most areas apparently because of the introduction of better forage crops although other factors may also have been important. However, the practice continued well into this century in areas where land pressure was severe and during dry years, and can occasionally still be seen today. These Central European studies started to provide data on monthly variation in leaf and twig biomass and in chemical composition, and on the digestibility of different plant parts. Results from chemical analyses were found to broadly support traditional lopping regimes. Although not backed up by experimental evidence, recommendations were given for different species concerning cutting cycles, type and time of harvesting (stem lopping, pollarding), storage methods (drying, fermenting) and feed preparation (boiling, mashing). There were considerable regional variations in these techniques and surprisingly, also in opinions concerning the relative feed quality of different species. *Castanea vesca* for instance was generally not valued as fodder but was indispensable in the Cévennes. Harvesting was often carried out by children, and tree ownership and rights varied considerably: in some parts of the Swiss Jura each fodder tree on common land was numbered and the year's leaf production auctioned for private harvesting.

European colonization led to further movement of fodder tree germplasm: *Leucaena leucocephala* was introduced to the Philippines from Mexico before 1800 (NAS, 1977). A widespread poor understanding of the ecosystem sometimes combined with disastrous results from inappropriate farm production systems and techniques, increasingly promoted research in some countries to look at the role of fodder trees in livestock production

and to develop appropriate management strategies for the tree/pasture/livestock complex in different environments (e.g. Everist, 1949, in Australia; Henrici, 1935, in South Africa). In the United States, the need to develop sustainable land husbandry in areas which were being severely degraded led to experimentation in the early 1900's with tree crops, and particularly fruit fodder producing trees for various ecozones. Special emphasis was given to hilly regions and areas with shallow soils or low rainfall (Russell-Smith, 1929). The potential of species selection and genetic improvement for advantageous characteristics such as fruit yield and quality, consistency of annual production and appropriate time of fruiting in relation to availability of other fodder, was realized.

In other climates with pronounced seasons information was rapidly being gathered on fruit and foliar chemical composition, certain management aspects, the importance of fodder trees to livestock nutrition and various traditional patterns of ownership and rights. For India these topics were discussed by Gorrie (1937) and Momin and Ray (1943); Laurie (1939) further listed 389 species of fodder trees and tentatively classified these into "good", "medium" and "poor" species according to their popularity by farmers. The increasing realisation that probably more livestock feed predominantly on shrubs and trees, or at least on associations in which shrubs and trees play an important part, than on true grass and grass-legume pastures resulted in a worldwide survey of available information being published in 1947 (IAB, 1947).

#### 4. Conclusion

This brief and piecemeal survey of past reliance on fodder trees indicates clearly that for over 2000 years, there have been various periods when they have played an essential role in various agricultural systems. From the survey it is also possible to identify various important attributes of fodder trees: palatability and quality; coppicing or pollarding ability and resilience to recurrent harvesting; leaf retention and quality maintenance during dry and/or cold seasons; regularity of fruit production; ability to produce fodder out of reach of livestock; production capacity on sites unsuitable for food or fodder crops and compatibility or acceptable competition with other crops or fodder. The need for appropriate fodder trees resulted in deliberate introduction of exotic species and superior genetic material. Ownership, usage rights and regulations were often complex reflecting the importance of fodder trees in the rural economy. Management practices at times considered the need for sustainability of tree production. The need for tree fodder harvesting seems to have depended on high feed value to labour cost ratios.

### III. FODDER TREE PRODUCTION AND NUTRITIVE VALUE

#### A. INTRODUCTION

A large body of knowledge concerning various aspects of fodder trees has been gathered over the last decades by foresters, veterinarians, livestock and pasture production scientists, ecologists and anthropologists. Comprehensive lists of species used by domestic and wild animals exist for many parts of the world, often including information on chemical composition and relative palatability to different animal types (eg. an

early worldwide survey, IAB, 1947; Africa, Le Houérou, 1980a; Indian subcontinent, Panday, 1982; Singh, 1982; Australia, Everist, 1969, and more are reviewed by Torres, 1983). ICRAF is developing a data base to include a world coverage of information on the feed value of fodder trees (Robinson, 1984). Although all available information has not yet been processed, at present the database contains 1550 records covering c. 550 species.

Opinions concerning the value of fodder trees in aiding animal production obviously varies enormously between different geographical areas and land management systems. (Fodder production is of course only one criterion in any such evaluation). They range from a view that trees are so detrimental to livestock production that they should be eradicated - eg. in the case of mesquite in the South Western USA (Martin, 1975), to having such potential that they could with breeding, selection and improvement "revolutionize the entire agriculture of the semiarid tropics" (West, 1950, cited in Gray, 1970). Further the same species may be viewed quite differently between areas:- in India, 46 out of the 389 species listed by Laurie (1939) were classed as providing good fodder in some areas and poor or medium poor fodder in other areas. Neem (Azadirachta indica A. Juss) is ignored by livestock, including goats, in West Africa (NAS 1980), while in India it is considered to be a good fodder tree and is intensively lopped to feed goats (Singh, 1982). But even within the same system opinion on the general value of trees is often completely contradictory: Martin (1975) advocates the eradication of mesquite (Prosopis spp.) from the semi desert range areas of the South Western USA in order to increase pasture production, while a few Texan farmers find on the contrary that with appropriate management of vegetation and livestock, the presence of a certain proportion of mesquite (Prosopis glandulosa var. glandulosa) and of other woody legumes is beneficial and helps improve livestock and game productivity (Maltsberger, 1983 and pers. comm.). Some genetic differences between the neems and the mesquites or between the animals may explain part of the differences in the value of trees to livestock. Nevertheless, these and many more contradictions highlight the danger of trying to predict what the value of a fodder tree may be from one area to the next - and even within the same areas when management regimes are different. However, keeping in mind these difficulties in making a generalized evaluation of a species without reference to its application in specific systems, it is possible still to discuss a number of distinct attributes of fodder trees under the headings "Biology and Primary Production" and "Nutritive Value".

## B. BIOLOGY AND PRIMARY PRODUCTIVITY

Average yearly tree foliar or pod biomass production figures are not useful measures of the contribution of primary production to secondary production. The more relevant measures are those which show the feed biomass availability at the time of selection by livestock or at the time of lopping both of which are site and time specific. However, only a few studies have included phenological descriptions (eg. Panday, 1982; Piot et al; 1980; Singh, 1982).

### 1. Influences of the environment on productivity

On the Indian subcontinent, many species are in leaf for a considerable

part of the dry season (eg. Singh, 1982). The onset of leaf production in fodder species in the African tropics and subtropics is often well before the onset of the rains; it usually continues long after they have stopped and the herbaceous plants have died out. Pod or fruit production also often occur during or at the end of the dry season. Acacia albida and some Capparidaceae (eg. Boscia senegalensis) start foliar production towards the end of the rains or in the early dry season (ILCA, 1982a, Piot et al., 1980).

The determination of allometric relationships between various tree characters has helped in the assessment of biomass, but the regression curves must be developed for different species and may not necessarily be applicable between regions even for a given species (Bille, 1980). Nevertheless foliar production estimates for the sahelian zone show a sharp increase in tree foliar biomass from c. 60 kg per ha (with less than 5% canopy cover) at the 400 mm isohyet to 1100 kg per ha (c. 45% canopy cover) at the 1100 mm isohyet (Penning de Vries and Djiteye, 1982). Yearly foliar productivity rates for several savanna woodland types in Africa are c. 1500 kg per ha, while a yield of 5000 kg per ha per year has been derived from a riverine Acacia xanthophloea woodland (Pellew, 1980).

Variations between years are also important and may differ in extent even within species for different size categories. In the Sahel, Bille (1980) found that during a severe drought year the average leaf and fruit biomass for 5 species was only 30% of that in "normal" years. However, between the species there were considerable differences in the degree of variation. In Upper Volta, a number of browse species could be grouped into those which are relatively insensitive to differences in climatic conditions (eg. Zizyphus mauritiana) and those which mirror the variations in environmental conditions (Grouzis and Sicot, 1980). Data from Zambia suggest that within year variations in the leaf biomass of quasi evergreen foliage may be considerable in some species (Bille, 1980). Nevertheless the within year and between year variations in leaf production amongst fodder trees are suggested to be much smaller than those in the herbaceous layer (Torres, 1983). Pod production variation may respond to adverse climatic conditions in a favourable way from the livestock's point of view (eg. Prosopis glandulosa var. glandulosa in Texas, Maltzberger, pers. comm.).

The proportion of production from different species which is actually used by livestock and game varies with time of year, stocking density, livestock type, height of the crown, accessibility within the crown and availability of water and alternative fodder. Hence in areas where the reliance on fodder trees is only for drought years (eg. Acacia aneura in Australia) the effective productivity is the amount of leaf accumulated without browsing over several years (Wilson and Harrington, 1980). Man can intervene to increase the access to leaf (lopping) or to pods (shaking).

## 2. Influences of harvesting on productivity

Within and between year production varies also with a number of other factors related to applied management. Based on experiences with other

tree crops, Cannell (1983) has suggested various theoretical fodder tree yield responses to different manipulative regimes. The removal of old shoots and leaves might result in no decrease in yields and sometimes even in improved yields; the proportion of leaf to stem production should be increased by keeping the size of the tree small and by encouraging branching; regrowth of new shoots following lopping should be less vigorous with increased distance from the roots; trees which recover poorly after coppicing might recover better after pollarding.

Different stripping regimes applied to 3 sahelian fodder species (Combretum aculeatum, Feretia apodanthera and Cadaba farinosa during the period of growth gave considerable variation in response between species. The highest cumulative foliage production was obtained with controls (no stripping) by Combretum and Cadaba, and with partial stripping every month by Feretia (Cisse, 1980). In the case of Feretia, total stripping monthly also out-yielded the control by 30% while in the case of Combretum it resulted in a 58% yield reduction over the control. Within a given year, the date of first stripping also influenced the species differently even taking into account the inherent differences in phenological development of the species rather than calendar dates. Total stripping every 15 days showed the lowest cumulative production in all 3 species. The depressing influence of monthly stripping during the whole growth period was still felt in Combretum and Cadaba a year later. However, the effect of regular total stripping regimes on the yields of each species in the subsequent year was also shown to depend on the time during the previous growing season when stripping was first applied:- when stripped during the phase of declining production Cadaba did not recover well the following year while Combretum recovered so well that it outyielded the control the following year by 99%.

Studies in Libya on the regrowth of a number of shrubs following cropping down to 10-50 cm above the ground showed that autumn/winter cutting resulted in regrowth almost as large as the foliage available from untreated shrubs while spring harvesting was detrimental to growth. Furthermore the regrowth was more palatable than old growth and 20-30% richer in nitrogen (Le Houérou, 1983).

In India, circumstantial evidence from several tree species had suggested for a long time that several years of rest were necessary between loppings in order to maintain fodder yields (Gorrie, 1937). Yet for some species, such as Khejri (Prosopis cineraria), there has been contradictory evidence. Khejri is traditionally lopped in winter (leaf emergence is in summer), often completely except for a branch at the top, and in many areas annually (Saxena, 1980, Singh, 1982). Lopping starts when the tree is c. 10 years old and a moderately sized tree yields 25 to 45 kg of dry leaf forage annually (Bohra and Ghosh, 1980; Ganguli et al. 1964). Ganguli et al. (1964) stated that Khejri could withstand recurrent and severe lopping without detriment to its growth or leaf yields, while Saxena (1980) suggests that such treatments affect the normal growth of the tree and that sometimes they die as a result. The number of lopping trials carried out to suggest optimum lopping cycles and intensities is however desperately small.

In Rajasthan, a trial using 8 Khejri trees per treatment with the following lopping intensities each year - complete lopping except for the leading shoot, lower 2/3 and lower 1/3 of the canopy, and control - over 4

years showed that the average yields were more than twice as large in completely lopped trees as for trees lopped to 2/3 of the crown (Bhimaya et al., 1964). Although initial tree height and girth data are not provided, end of trial figures on DBH and tree heights suggest to the authors a greater increment in DBH and heights in completely lopped trees compared to other treatments and to the control. Observations on the effect of a 4 year rest period suggested to the authors that it was necessary, particularly for smaller trees. Analysing the results by different diameter classes, the smaller trees (DBH 20-25 cm), which had rested for 4 years, showed a 238% higher leaf production over the annual production of those lopped annually; the larger trees (DBH 35-40 cm) showed only a 161% increase in yield. This suggests that larger trees may be able to cope better with recurrent lopping. The results also explain why farmers lop annually since it would require an increase in yield of more than 400% by rested trees to attract them to a 4 year lopping cycle. In Haryana, however, completely lopped trees showed a generally higher annual harvest than trees which were harvested every 2 or 3 years (Srivastava, 1978). For the farmer, annual lopping would therefore provide more than 3 times as much fodder as the annual harvest on a 3 year lopping cycle. There are however questions as to the ways in which the trees were lopped in the two studies since there were considerable differences in annual yields between the two studies, even for trees of similar stem diameter categories; further in both studies the fresh weight yields were considerably lower than the dry weight yields quoted earlier and which are said to be the norm.

A lopping trial on Schima wallichii in Nepal suggests that the removal of the lower 80% of crown length results in a DBH increment of only 20% of that in unlopped trees over the next year (Mohns, 1984). In this case the lopping was done on 12 year old trees and following local practice, at the end of leaf flush (end of the dry season).

In Leucaena leucocephala, the influence of cutting height on foliage production has shown varying results. Pound and Cairo (1983) suggest that height of cut can be very low in Hawaiian - type varieties, while for Peru and Salvador cultivars the situation is different since a higher proportion of branches are born higher on the plant. However, the situation does not seem to be clear. For an Hawaiian type they quote data showing that out of a range of cutting height from 0 to 76 cm, the 0-5 cm height cut produced most fresh material. Yet others working with Hawaiian types have found different results. Using cutting cycles ranging from 40 to 120 days, Pathak et al. (1980) showed that the best forage yields were with 30 cm cutting height (in a treatment range of 10 to 30 cm cutting height). Krishna Murti and Mune Gourda (1982) found a maximum yield at cutting height of 150 cm (in a treatment range of 15 to 150 cm and at cutting frequencies of 40 to 70 days). Pathak et al. (1980) suggested that the 30 cm cutting height provides more space on the shoot for branching leading to increased browse production. For a Peru variety in Mauritius, Osman (1981) found that a 90 cm cutting height (out of a treatment range from 15 cm to 150 cm) gave the largest dry matter production on a 90 day cutting cycle. Mendoza et al. (1983) in the Philippines on the other hand, also for a Peru variety, found for a range of cutting frequencies (65-110 days) that a 300 cm cutting height gave the best herbage (d. wt.) and crude protein yields per year from a treatment range of 15 cm to 300 cm cutting height.

It has been known for a long time that some shrubs are more susceptible to defoliation than others, and root growth studies may help explain responses (Hodgkinson and Baas Becking, 1977). Site characteristics such as soil fertility, soil moisture regime etc. are known to have a bearing on the way species respond to different rates of defoliation (eg. Jones and Harrison 1980).

### 3. Pod production

Information on pod production is scarce. Some Prosopis and Acacia species may yield 3-10 t per ha in different ecological zones (Torres, 1983). However, information on yearly fluctuations in pod yield are even scarcer. The contribution of inherent genetic factors, of environmental factors and of tree manipulation to such variation in pod yields is likely to vary considerably in different species. (eg. Felker, 1983).

### 4. Population trends

Any trends in overall production over time are partly a function of the population trends for the various species which make up the community. Little information is available on the way in which the factors influence the development of most plant communities: however, factors such as fire frequency and timing, climate and its variability, grazing and browsing pressures and their timing and soil compaction are known to be important. The proportions and densities of different types of livestock and game are crucial in determining a community structure, particularly grazer to browser ratios (eg. Aucamp, 1978; Lange and Willcocks, 1980; Lesperance et al; 1970; Staples, 1942). Populations of good fodder tree species may regenerate at slower rates than they should to maintain their contribution to the system, or may even die out (eg. Chippendale, 1963; Seif el Din and Obeid, 1971).

### 5. Tree pasture mixes

The influence of fodder trees on the seasonal production of the understorey is also important (see Fig. 1):- Some tree species have a beneficial influence on the total yearly understorey production, at least when the canopy is managed appropriately (eg. Hardwickia binata and Zizyphus nummularia in Rajasthan; Bahiti, 1981); some species may have a variable influence depending on their age/size (which may be partly a function of a difference in tree densities for different size categories); and finally some species have a detrimental effect even at very low densities (eg. Acacia aneura in Australia; Beale, 1973). The degree of tree pasture influences and even their nature may vary between years depending on climatic fluctuations (eg. Walker, 1974).

However reduction in total annual pasture production does not necessarily result in reduced secondary production:- Although the tree fodder production may not compensate in terms of quantity for the production lost in the pasture component, the quality of forage is often better (for in many pastures there is anyway often a surplus of standing and largely unpalatable herbage biomass during the dry season); for a well balanced mixed tree-pasture system, the total production, although it may be less than in a purely pasture system, may also be better distributed over time with the onset of pasture growth occurring earlier and continuing later (eg. Goldson, 1973; Kennard and Walker, 1973).

So while some fodder trees could be successfully integrated with pasture, those which are known to be detrimental to useful pasture production and are still beneficial to the overall system, should ideally be kept segregated within the same system (eg. Acacia aneura stands for drought reserves; Pressland, 1975). Similarly in cropping systems a number of fodder trees can be and are associated with food or fodder crops without affecting crop yields (eg. Leucaena leucocephala, Sesbania sesban, Gill et al. 1983; Venkateswarlu et al., 1981). Where crop yields are negatively affected, appropriate manipulation and spacial arrangement of trees may reduce the problem.

## 6. Conclusion

The foregoing discussion on primary productivity of fodder trees and of fodder tree pasture systems suggests serious problems for the evaluation of their role in livestock production:- There is frequently a lack of agreement concerning tree responses to various treatments even for the species which are supposed to be better understood. This may be due to several reasons which include:

- 1 the very variable site characteristics of the various trials. (These are anyway seldom described in enough detail to clarify the causes of observed differences);
- 2 the variations which are likely to occur in the ways that individual plants or populations are actually manipulated, even when they appear to be manipulated in the same way (eg. how many people would lop 2/3 of a canopy in exactly the same way?).
- 3 the likelihood that many species of fodder trees may show wide genetic variability.

Lastly most of the studies investigating the influences of defoliation on subsequent productivity have only been carried out over a small number of years and therefore preclude realistic predictions of likely long term effects.

## C. NUTRITIVE VALUE

As much could be said about the problems of evaluating the nutritive value of fodder trees as about those concerning their productivity; however, since the topic has been well covered elsewhere ( eg. Le Houérou 1980a; Torres, 1983; Wilson, 1969) only a brief outline follows.

The average chemical composition of tree foliage or pods - the measure most frequently given in assessments of feed value - cannot realistically be related to a tree's importance to animal nutrition. Nutritive value is a function of palatability, intake, digestibility of the various chemical constituents as well as of chemical composition. These attributes vary with time in any given species. Generally we can say that the effective nutritive value depends on any combination of:- the tree species, and variations over time and between parts of a given tree; the animal species and individual variation within animal species. Also the value of any particular feed component in a given animal's diet is dependent on the characteristics of all the other various components in



its diet at that time; and these include tree-pasture components, feed or mineral concentrates and water availability. Finally even for one particular component in a given animal's diet, the interactions between constituent chemical components within the animal may affect useful nutritional value (eg. high tannin contents usually result in low crude protein -CP- digestibility -eg Lohan, et al. 1980).

All the above points suggest that the use of standard "objective" units of nutritional value is highly suspect in terms of actual value to the animal. Summarizing available information from in vivo digestibility studies, Torres (1984) has found that the rate of increase in CP digestibility with increasing CP content in woody perennials is lower than that found in herbaceous forage and the CP digestibility for tree foliage may vary from 15.6 to 82.2%. Although in vivo digestibility studies have been found to provide the only realistic assessment of the value of tree fodder, the cost of carrying them out and the demand on resources is very high.

Nevertheless we can positively say that in general, the better fodder trees (for leaf or pod production) have relatively high CP levels which are maintained during the period when alternative feed sources have low CP values. Le Houérou (1980b) has reviewed a large number of tree foliar analyses from Africa: the average CP values for all browse species for West and East Africa are 12.5% and 13.3% respectively. This is considerably higher than an average yearly value for pasture; while the value for legumes is 14.8 and 16.8 respectively, the Capparidaceae have CP levels of 20.7 in both West and East Africa. Since these are averages, the leaves of some species clearly have higher CP contents; for instance several studies with Gliricidia sepium (syn G. maculata) show a range from 18.8% to 30.0% CP (% DM) (Lindsay Falvey, 1982b). Further the ability of livestock to select leaves with much higher CP levels than shown in average values for a population is well documented (eg. Wilson, 1969).

The tree foliage of some species can be fed to livestock as sole feed but the resulting performance of the animals is usually sub-optimal (eg. Gliricidia sepium; Carew, 1980). However, during drought when no other feed is available, the supply of such feed may maintain livestock weights where otherwise livestock would die. Further several species have been found to improve the productivity of stock when their fodder is available as a supplement to a diet which includes otherwise low quality feeds (eg. Leucaena leucocephala, Jones, 1979; Rosas et al. 1981; Gliricidia sepium, Chadhokar and Kantharaju, 1980). The rôle of some fodder trees in improving the overall utilisation efficiency (both in terms of intake and digestibility) of low quality herbage and crop residues is therefore particularly important.

#### IV. LIVESTOCK PERFORMANCE AND NUTRITION

With few exceptions (mainly in the wet tropics), livestock in tropical, subtropical, mediterranean and alpine environments live for considerable periods of the year on sub-maintenance diets (for various regions and ecozones see eg: Alden, 1982; Crowder and Chedda, 1982; Dutt, 1979; ILCA, 1979, 1982a, 1982b; Lindsay Falvey, 1982a; Mahadevan, 1982; 't Mannetje, 1982; McLean et al. 1983; Mosi et al., 1976; Potter, 1982).

The genetic potential of livestock is therefore not realized. Combined with disease (which can frequently be associated to low nutrition levels), this results in poor growth rates, delayed reproductive maturity, low birth rates, high adult and immature mortality, low milk production, and a cropping system in which animals are too weak at the end of the dry season to perform their functions (eg. ILCA, 1982b; Raintree, 1983; Roth and Newman, 1978).

The minimum crude protein (CP) requirement is c. 9% for ruminant maintenance and c. 15% for lactation and growth (Norton, 1982). Nutritive quality of natural swards show considerable seasonal variation. Chemical analyses of herbage from a large number of grasslands in the tropics and subtropics have indicated an average CP content during the dry season of 3-4%, occasionally even lower towards the end of the season (eg. Hacker, 1982; Crowder and Chheda, 1982). During the wet season, average pasture CP levels, although usually adequate for maintenance and some weight gains, are insufficient for maximum production. Average mineral values are also often well below requirements, particularly for phosphorus and vitamin A during the dry season. In some natural grazing areas however, provided stocking densities are low enough, interplant and inter-specific selection of grazing plants by livestock means that maintenance requirements or better can be obtained during the dry season (Potter, 1982). Nevertheless several studies under natural grazing conditions have shown that low CP intake levels due to low average CP levels is the major limiting factor in livestock production. (eg. Pratchett, 1977; Torres, 1983). In a subhumid to semi arid area of West Africa, regression analysis of liveweight changes showed a strong correlation ( $r=0.89$ ) with CP intake (Lambourne et al., 1983).

The fodder problem of many mixed farming systems may be both an acute shortage and a low quality (eg. Potter, 1982; Raintree, 1983). For instance in India and Pakistan, the national average shortfalls in meeting the livestock nutritional requirements are 40-50%. For Asia and the Far East the average area of permanent pasture is 0.12 ha per ruminant livestock unit and in India the average area devoted to forage crop production is .033 ha per animal (Mahadevan, 1982). Hence the main feed resource base of many such systems consists of crop residues. In parts of Nepal and of Northern Nigeria, the yearly contribution of crop residues is c. 50% and over 80% of forage supply respectively (ILCA, 1979; Wyatt-Smith, 1982). The nutritive value of commonly grown grain crop residues is low, CP levels ranging from c. 2% to c. 6% (Burns, 1982; ILCA, 1979; Ranjhan and Khera, 1976, Sen et al., 1978); while that of some leguminous crop residues is reasonably high (eg. c. 10-12%), the proportion of cropped area planted to legumes is not often of much consequence. Further the low dry matter digestibility (DMD), ranging from 30-50%, of most crop residues limits their value as sole feeds (Burns, 1982).

Low dietary CP levels reduce the overall digestibility of herbage dry matter, the total digestible energy content and, when it falls below c. 7%, the voluntary intake of dry matter (Crowder and Chheda, 1982; Wilson, 1982).

Technically, improvements in livestock nutrition and performance can be achieved in various ways: with the supplementation of the diet with mineral licks, urea and protein concentrates; with treatment (eg. with

alkalis) to increase the digestibility and/or palatability of low quality forages - especially crop residues; with the introduction in the pasture of herbaceous legumes which have higher CP levels and for a longer period than the indigenous pasture. However, in most situations in developing countries, these innovations have for various reasons been found to be uneconomic and unsuccessful (eg. ILCA, 1979; Potter, 1982; Pratt and Gwynne, 1977). Some improvements in livestock nutrition can be achieved in range areas by appropriate management of existing resources; these include appropriate stocking densities in different seasons, the careful use of fire and variations in the proportions of the various livestock types (eg. Evans, 1982). Dry season fodder reserve areas have traditionally been used in many pastoral societies but without a tree fodder component the CP intake are at sub-maintenance levels except at very low livestock densities. In mixed farming systems of the sub humid zones, the introduction of herbaceous legumes which do not compete with crops, either by being planted on unutilized areas within crop lands (eg. terrace banks) or by relay cropping (eg. with various *Stylosanthes* varieties; ILCA, 1982b), can also help to improve the nutritional status of livestock.

A more efficient utilisation of the natural vegetation (including fodder trees) in terms of secondary production, could also be achieved by the introduction of different types and mixes of animals such as camel, giraffe, water buffalo and other domesticated and non-domesticated species (eg. NAS, 1981; 1983; Pellet, 1980). However there are a number of technical and social problems impeding their introduction.

It seems therefore clear that technically, fodder trees have an important role to play in the supplementation of low quality forages, even if other means of improvements in livestock nutrition are introduced; both the efficiency of utilisation of a system and overall livestock productivity can thereby be improved.

#### V THE ACTUAL, POTENTIAL AND FUTURE ROLE OF FODDER TREES

Any attempt to evaluate the role of fodder trees in farming systems must try to answer a number of questions.

##### a) Present role

What is the nature and extent of:

- i) their contribution to the various production and service (e.g. provision of manure) functions of livestock? (e.g. Bernstein et al, 1983; Robinson, 1983; Roth and Norman, 1978). In many parts of the world some farming systems would collapse without fodder trees. For a pastoralist situation, Le Houérou (1980c) has described a trial with livestock in the Sahel which aimed to look at the different performance between a group of livestock which had no access to fodder trees and one which did: the trial had to be discontinued because the livestock in the area with no fodder trees would have died. In mixed farming systems such as found in many parts of the Indian subcontinent and Africa, livestock are already on sub-maintenance diets at times of year when tree fodder is a major component of their diet (see fig. 2) (eg. Dutt, 1979; Mohns, 1981; Negi, 1983; Wyatt-Smith, 1982).

ii) their interaction with other farm production subsystems? (e.g. labour demand, direct influence on crops when intercropped).

b) Potential role

- i) What are the factors which limit the productivity of the livestock and other subsystems?
- ii) What are the attributes of fodder trees which help to alleviate these limitations and improve productivity?
- iii) What spatial arrangements and management regimes are likely to be most appropriate and how can the implementation of proposals be achieved?

c) Future role

Further questions will include:

- i) What is the likely demand for the various production and service roles of livestock?
- ii) Are there any attributes of fodder trees which look as if they can be improved?
- iii) What changes are likely to take place in the various subsystems and how will these influence the value of fodder trees in relation to the efficiency of the whole system?

Although in developed countries reduced levels of production in the livestock sector are sometimes suggested, the situation in poorer countries with regard to future livestock demand is likely to be very different. The demand for the various livestock functions must increase with human population growth. It is doubtful whether alternative technologies and modes of production can replace livestock in these roles to any significant extent. Draft animal power is already inadequate, the shortage is acute in some areas (e.g. much of South East Asia) (Mahadevan, 1982), and demand is expected to increase by 0.8% per year in the future (Bernsten et al., 1983). A less optimistic scenario investigated to the year 2000 by FAO suggests an 80% increase in animal production (cattle, sheep and goats) with an increase in livestock numbers of 15% (FAO, 1981). Yet, with few exceptions, any increase in animal production over the last 50 years has been mainly due to livestock numbers and not improved productivity (Mahadevan, 1982). Shortening fallow cycles and addition of increasingly marginal land to the world's cropland base will necessitate a greater manure input to sustain yields (improved crop rotations and mixtures and agroforestry technologies should also contribute to the sustainability). Yet in many cropping areas yields are already dropping (e.g. Bajracharya, 1983 for Nepal; Brown, 1978; Ruthenberg, 1980). Furthermore any addition to cropland is often at the expense of the very areas on which livestock rely for dry/cold season grazing and this erosion of the feed base may make it impossible to sustain the very animals on which continued cropping depends.

## VI CONCLUSION

The trends concerning agricultural development - or perhaps rather the expected production demands from agricultural systems - in developing

countries point towards situations where fodder trees could play an increasingly important role. In mixed farming systems where fodder trees are already in use on croplands, their production is insufficient to meet the demands; more trees are required but information is needed on species which can be associated with crops without causing a reduction in crop yields, and on appropriate management of the trees in such situations. In rangelands the problems of tree establishment are very complex; a better understanding is required of the factors which create the right conditions for regeneration of appropriate species, and of the livestock types, combinations and densities which promote desirable plant species mixes. Large dry season fodder reserves which include fodder trees can successfully be established in pastoral areas, given the will of the pastoralists to do so and appropriate support from the authorities.

A list of the better fodder tree species for different environmental and management conditions is urgently required so that more detailed investigations can be initiated: to obtain optimum contributions from fodder trees, a lot more needs to be understood about their response to various management regimes in different environments; because responses seem to vary considerably, this will require a large research input. Cheaper and more meaningful methods of determining fodder tree value for different animal types would be welcome. Plant breeders have already been assigned to fodder tree improvement projects; but what characteristics are they going to select for? (eg. mainly leaf or mainly pod production; maximum leaf production for the years with good precipitation, or capacity to survive and retain leaves during dry years). What will the consequences of such selection and breeding be on other tree characteristics? How will these changes be expressed in different environments and management situations?

The problem of overgrazing in pastoral areas is linked to complex socio-economic and political factors, and these need to be understood and tackled before technical improvements are introduced. Finally, a reductionist research approach looking at individual components of the complex farming systems which include fodder trees must go hand in hand with a systems approach; technical solutions must be found, but to the right problem, and problems will vary in nature with the very varied situations one is dealing with.

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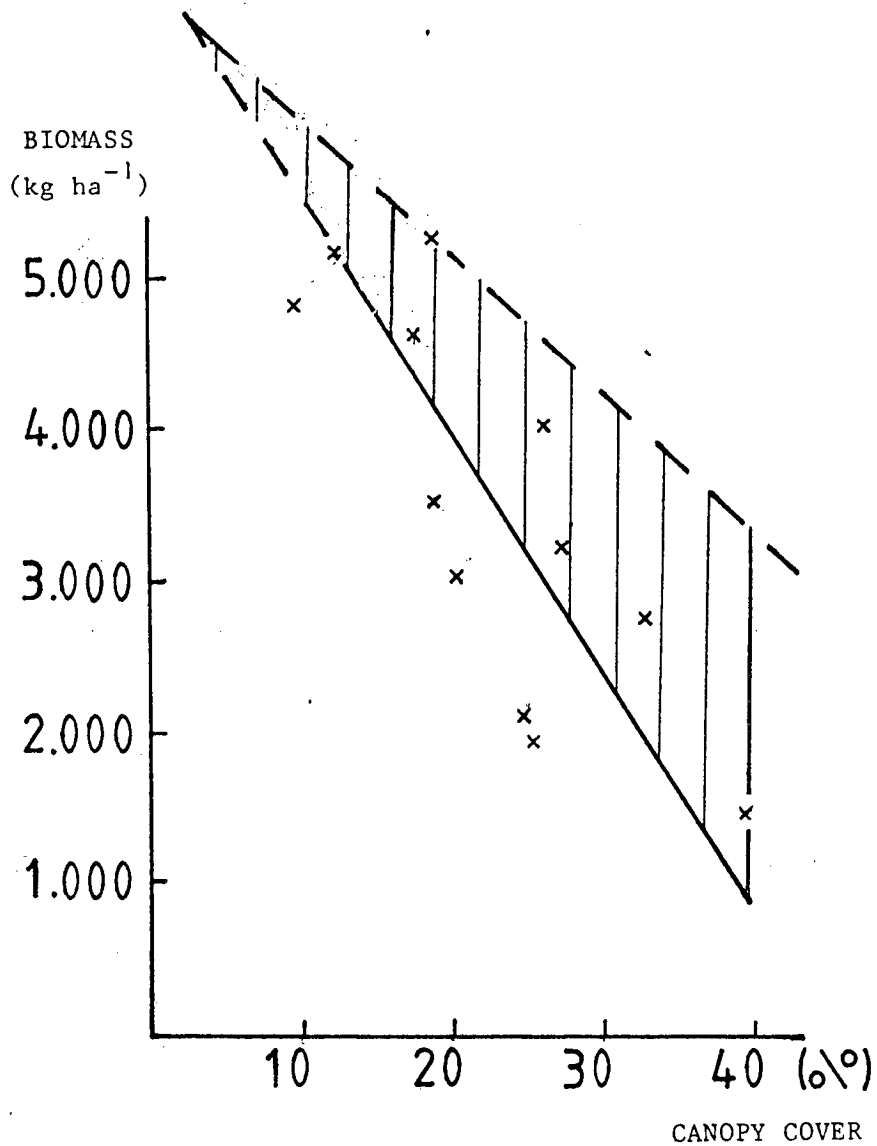


Fig. 1. Annual production of the herbaceous stratum as a function of the canopy cover of woody species (x) and an estimate of the mean foliar production of trees (hatched area) for an isohyet of 1100 m at Satuba (Sahel) (from Penning de Vries and Djiteye, 1982).

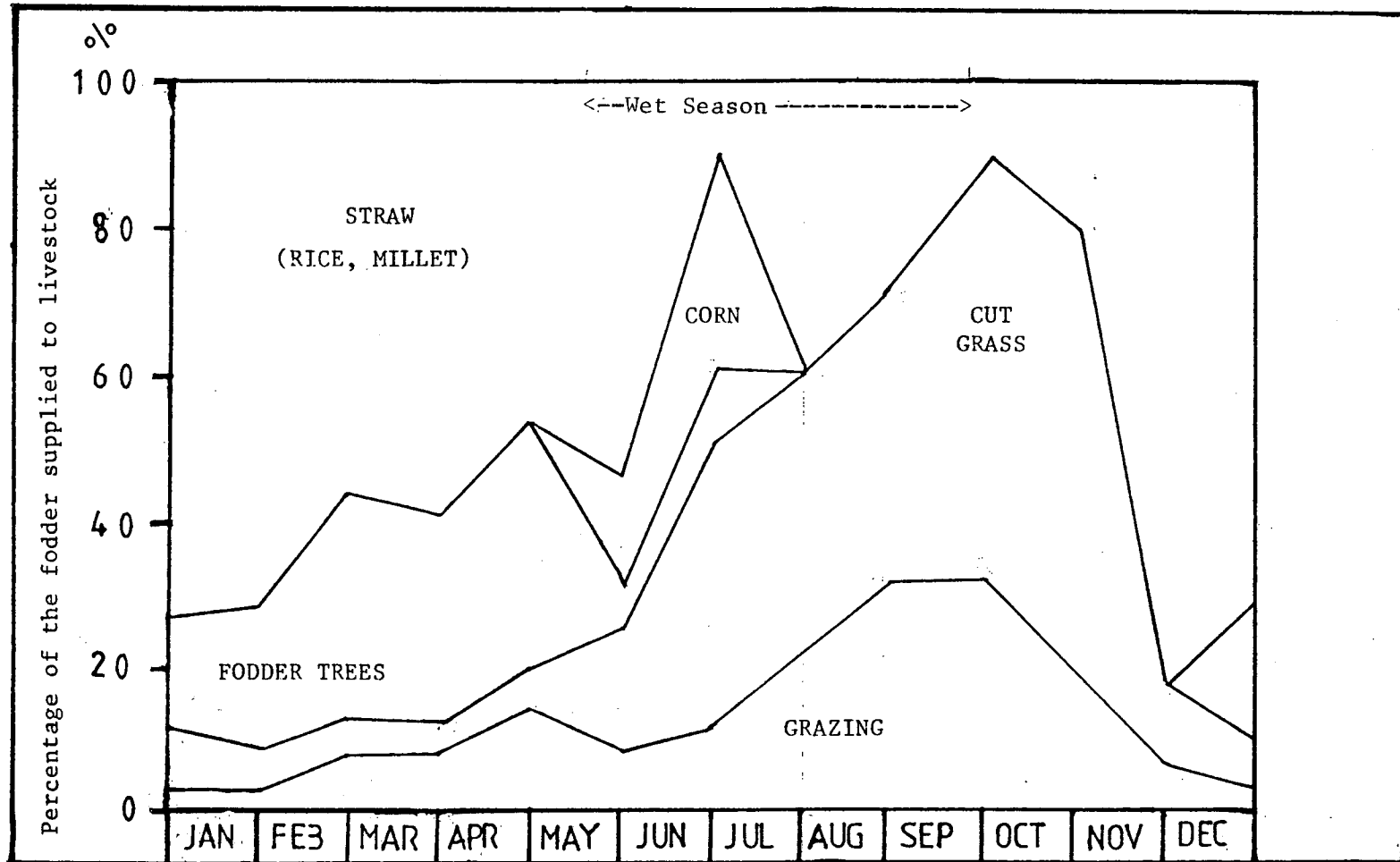


Fig. 2. Seasonal variation of the forage supplied to livestock in a hilly area of Eastern Nepal (from Mohns, 1981 quoting Hager, 1978).

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ANNEXE III

"Data Base on Fodder Tree Chemical  
Composition and Feed Value"

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UNITED KINGDOM

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#### DATA BASE ON FODDER TREE CHEMICAL COMPOSITION AND FEED VALUE

The increasing interest in multipurpose trees for productive and sustainable land management systems has created an urgent need for quantitative information on the characteristics of various tree and shrub species. Such information is important for making rational choices concerning the suitability of particular species for specific sites and functional requirements.

Hence the development of data bases and their management for quick retrieval of information is an important component of programmes in institutions which have an advisory role on research and development in the rural sector. Within its documentation and information services programme, ICRAF has identified a need to develop various computerised data bases to enable efficient information storage and dissemination.

In the past a number of comprehensive regional/national reviews on fodder trees and shrubs have been published (e.g. IAB 1947, Le Houerou 1980, Pandey 1982, Singh 1982), while other publications on more general subjects contain considerable sections on such species (e.g. FAO 1981, NAS 1979). In order to make more effective use of such information, a computer data base on fodder tree/shrub chemical composition and feed value is being developed at ICRAF with cooperation from CFI (Oxford).

In the past years ICRAF has acquired more than 270 documents dealing specifically with the chemical composition of woody perennials, which are being examined for their relevance to feed value. The first task was to screen for original data to avoid duplication from different sources. To date, 981 records are on computer and a further approximately 1000 are being processed. Each record consists of a data set for a particular species, derived from either one or several analyses. For the latter, an average is calculated when the results of the analyses can be amalgamated into meaningful groups (e.g. grouping monthly values by broad season); some species therefore have many records. Not all species in the data base are nitrogen fixers, but a considerable proportion belong to taxonomic groups in which some species are known to fix nitrogen (320 records are from the Leguminosae).

The intraspecific variation in chemical composition can sometimes be considerable and reasons for this may be numerous (e.g. ecological zone, season of sampling, phenological stage of development, plant part, inherent genetic differences between individuals and provenances). Reviews of original literature which provide average values may mask the valuable differences which may occur within species. Hence available data have been arranged according to geographical region, country, ecozone, season and plant part (see fields 4-8 in the annotated structure below and the record sample - Annexes I and II).

\* as of 15 April 1984, 1550 records covering c.550 species

Unfortunately, most data are in the form of chemical composition as determined by the proximate analysis (Weende System) with its well documented unreliability as a predictor of feed value. Nevertheless the analytical procedures are standardized (and therefore values are comparable). Thus, those chemical constituents which are frequently assessed and have more relevance to feed value are those which have been included in the form of quantitative information (fields 9-14).

Information on other parameters which are less often reported and/or for which the methodology is not standardized and therefore usually not comparable is included in fields 19-24. These fields indicate whether or not information is available under those headings in the original publication.

The process of screening the information for inclusion in the data base has indicated the extent to which some research workers still follow unsatisfactory investigational procedures (e.g. low number of samples) and often, little information is given concerning the methodology of investigation (e.g. season of sampling and procedures), the site description (e.g. climate) and description of the plant parts sampled.

There will undoubtedly be room for improvement in terms of structure and content of the data base, and suggestions from interested individuals and institutions would be welcome. Contributions of information on fodder trees and shrubs from unpublished reports and literature would also be welcome so as to improve the usefulness of the data base. However, this data base is only one amongst several interacting data bases being developed at ICRAF; each individual data base being complementary to the others and possessing interactive linkages. The data base is on the Osborne microcomputer in dBASE II format. dBASE II is a data base management package produced by Ashton Tate and is available for a wide variety of microcomputers. The Osborne uses 5 1/4 inch single sided, double density soft sector floppy diskettes. With some modifications the data base could also be used on other CP/M 80 base systems.

Comments, unpublished information and requests should be sent to INFORMATION SERVICES / ICRAF / P.O. Box 30677 / Nairobi, Kenya.

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ANNEXE I

## ANNOTATED RECORD STRUCTURE OF dBASE II FILE FTCDMP.DBF

NO.	FIELD NAME	TYPE	WIDTH	DEC	REMARKS
1	BIBLNO	C	4	0	
2	SPECIES	C	70	0	
3	FAMILY	C	22	0	
4	GEOGREG	C	1	0	* 13 GEOGRAPHICAL REGIONS
5	COUNTRY	C	2	0	*
6	ECOZONE	C	10	0	* 8 ECOZONES
7	SEASON	C	1	0	* TIME OF SAMPLING, 11 POSSIBLE SEASONS DUE TO DIFFERENT CLIMATIC PARAMETERS DETERMINING SEASONALITY
8	PLNTPART	C	9	0	* 3 PLANT PARTS AND 5 STAGES OF MATURITY
9	CRUDEPROT	N	4	1	
10	CRUDEFIBR	N	4	1	
11	TOTALASH	N	4	1	
12	PHOSPHOR	N	4	2	
13	CALCIUM	N	4	2	
14	NA	N	5	2	
15	ANIMAL	C	5	0	* 12 CATEGORIES
16	ANALYSNO	C	2	0	NO. OF ANALYSES FROM WHICH THE AVERAGE VALUES HAVE BEEN DERIVED
17	SAMPLENO	C	2	0	NO. OF SAMPLES (eg TREES, PLOTS) USED FOR EACH ANALYSIS
18	ORIGINAL	C	1	0	* ARE THE DATA ORIGINAL OR FROM SECONDARY SOURCE
19	INTAKE	C	1	0	& INTAKE OF BROWSE EITHER ALONE OR MIXED WITH OTHER FEED
20	PALATAB	C	1	0	& PALATABILITY
21	TOXICITY	C	1	0	& INCLUDES TOXICITY AND DIGESTIVE INHIBITORS eg TANNINS
22	WATERINT	C	1	0	& WATER INTAKE AS AFFECTED BY BROWSE INTAKE
23	PROTDIG	C	1	0	& PROTEIN DIGESTIBILITY
24	DMD	C	1	0	& DRY MATTER DIGESTIBILITY
25	PHENOLOG	C	1	0	& PHENOLOGY, PARTICULARLY TREES IN LEAF AND FRUITING TIMES
26	TIMEOFUSE	C	1	0	& TIME OF YEAR WHEN BROWSED OR LOPPED
27	QUAL	C	1	0	* GOOD FODDER SPECIES AS ASSESSED BY RESEARCHER OR LIVESTOCK OWNER ARE SINGLED OUT

## KEY

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FIELD NAME Major category or heading under which data retrieval will be required

TYPE Character (C) or Numeric (N) data

WIDTH Maximum number of characters or numbers

DEC Number of decimal places in numeric data

\* CODED BY ALPHABETIC LETTERS

&amp; CODED T IF ANY INFORMATION AVAILABLE IN THE PUBLICATION

BLANK IF NO INFORMATION AVAILABLE

ANNEXE IIEXAMPLE OF A RECORD

( SEE SAMPLE SHEET )

BIBLIO NO.	:	0039
SPECIES	:	Indigofera cliffordiana
FAMILY	:	Leguminosae, P
GEOGRAPHICAL REGION	:	E
COUNTRY	:	KE
ECOZONE	:	S
SEASON	:	W
PLANT PART	:	LO
CRUDE PROTEIN	:	18.4
CRUDE FIBRE	:	16.7
TOTAL ASH	:	18.8
PHOSPHORUS	:	0.00
CALCIUM	:	0.00
NA	:	0.00
ANIMAL	:	B
ANALYSIS NO.	:	01
SAMPLE NO.	:	
ORIGINAL	:	T
INTAKE	:	T
PALATABILITY	:	T
TOXICITY	:	
WATER INTAKE	:	
PROT DIG	:	T
DMD	:	T
PHENOLOGY	:	
TIME OF USE	:	
QUALITY	:	G