A review of the factors affecting the survival of donkeys in semi-arid regions of sub-Saharan Africa.

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Abstract

The large fluctuations seen in cattle populations during periods of drought in sub-Saharan Africa are not evident in the donkey population. Donkeys appear to have a survival advantage over cattle which is increasingly recognised by smallholder farmers in their selection of working animals. The donkey's survival advantages arise from both socio-economic and biological factors. Socio-economic factors include the maintenance of a low sustainable population of donkeys due to the single purpose role and their low social status. Also because donkeys are not generally used as a meat animal and can provide a regular income as a working animal, they are not slaughtered in response to drought as are cattle.

Donkeys have a range of physiological and behavioural adaptations that individually provide small survival advantages over cattle, but collectively may make a large difference to whether or not they survive drought. Donkeys have lower maintenance costs as a result of their size, and spend less energy whilst foraging for food; lower energy costs result in a lower DMI requirement. In donkeys, low quality diets are digested almost as efficiently as in ruminants, and because of a highly selective feeding strategy, the quality of diet obtained by donkeys in a given pasture is ligher than that obtained by cattle. Lower energy costs of walking, longer foraging times per day and ability to tolerate thirst may allow donkeys to access more remote, under-utilised sources of forage that are inaccessible to cattle on rangeland.

As donkeys become a more popular choice of working animal for farmers, specific management practices need to be devised that allow donkeys to fully maximise their natural survival advantages.

Introduction

Recurrent droughts in sub-Saharan Africa over the past two decades have resulted in heavy cattle losses, causing severe shortages of draught animal power. As a consequence smallholder farmers have become increasingly reliant on donkeys to provide on-farm power (Nengomasha *et al.* 1999). Farmers have identified donkeys as having superior survival characteristics in times of unreliable rainfall. Livestock census and weather data from Zimbabwe and Ethiopia (FAOSTAT 2002, Corbett *et al*. 2001) provide empirical support for farmers' belief in the superior survival characteristics of donkeys, with annual fluctuation of cattle and small ruminant populations closely following variations in annual rainfall but with donkey populations remaining stable (Figure 1 and 2).

This paper discusses the socio-economic, physiological and behavioural reasons for the superior drought survival characteristics of donkeys in order to identify opportunities for improvement of donkey management within small holder farming systems of sub-Saharan Africa.

Socio-economic factors

Figure 1 and 2 show large variations in ruminant livestock numbers in both Zimbabwe and Ethiopia; donkey numbers showed little variation during the same period. This does not necessarily indicate that donkeys are innately more able to survive periods of drought than ruminants, because these types of livestock are managed differently and play different roles within the communities which own them.

Both cattle and small ruminants have a value to African small holders that goes beyond there ability to provide food (Bayer and Waters-Bayer 1998). They are also kept as a form of wealth, food security and as an indicator of social status (Jahnke 1982). Generally donkeys are not kept in order to accumulate wealth and do not provide food security (Twerda *et al.* 1997). As a consequence of the low social status of donkeys and of their single purpose role within the farming system, few farmers keep more donkeys than are needed to fulfil their immediate work/power requirements (Tesfaye and Smith. 2000).

The overall population of donkeys in Ethiopia and Zimbabwe remains small compared to that of cattle and small ruminants (Table 1). The tendency of small-holder farmers to accumulate cattle and small ruminants during times-of-plenty leads to the long-term carrying capacity of communal rangeland being exceeded, then when rains fail cattle and small ruminants are vulnerable to starvation. On-the other hand, donkeys populations tend not to exceed long-term carrying capacity of communal pastures and their numbers are more sustainable.

The fall in cattle and small ruminant populations during drought is not entirely due to the 'unmanaged' death of animals. In times of poor rainfall the investment accumulated in farmers' herds are realised by selling animals for meat (White 1981). This managed decrease in the ruminant population explains most of the drop in population during low rainfall years (Doran *et al.* 1979). Donkey meat is not generally consumed, so they are not slaughtered or sold in response to drought (Tesfaye and Smith. 2000) firstly because this would provide little benefit to the farmer and secondly because a living donkey can provide a household with a regular source of income. In this respect donkeys are similar to dairy cattle which are usually the last animals to be sold in times of hardship (Tesfaye and Smith. 2000).

In periods of good rainfall there is not the same expansion in donkey numbers that is seen in the ruminant population. During times of drought, donkey populations do not fall as acutely as those of ruminants because they are not sold for meat in response to poor rains. The stability of the donkey numbers is in part explained by the maintenance of a necessary population during high rainfall years and in low rainfall years by their ability to contribution to the household economy without them being sold.

Physiological factors

Energetics

The energy cost of maintenance and work in donkeys has not been as comprehensively researched as it has with other species such as cattle and horses. Studies by Yousef and Dill (1969) and Yousef *et al.* (1972), using an ambulatory technique that collected exhaled gas in a weather balloon, measured energy costs of walking in 2 donkeys (0.98 J/m/kg) and 5 humans (1.84 J/m/kg). Dijkman (1992) reported similar values in 2 donkeys of 0.97 J/m/kg in treadmill studies. Pearson *et al.* (1998) reported values for the energy costs of walking in 3 donkeys (1.15 J/m/kg) and 3 ponies (1.25 J/m/kg) in treadmill studies and energy cost of standing in donkeys (4.06 W/kgM$^{0.75}$) and ponies (3.72 W/kgM$^{0.75}$). The same authors reported higher energy costs of walking measured in 3 donkeys (1.37 J/m/kg) in Tunisia using ambulatory equipment (OXYLOG) (Pearson *et al.* 1998). A total of 10 donkeys were used in all of the studies cited above and there were considerable differences both between and within studies in the techniques used to measure energy expenditure, results should be therefore be compared cautiously.

Smith *et al.* (1994) measured the energy costs of standing, walking and pulling in ponies and compared these to values measured in donkeys by Dijkman (1992) and in cattle by Lawrence and Stibbards (1990). The same equipment and techniques were used in each of the three studies allowing more confident comparison of results. The study of Smith *et al.* (1994) showed that the energy cost of standing was higher in donkeys (1.40 W/kg Lwt) than in ponies (1.93 W/kg Lwt) and cattle (1.12 W/kg Lwt).

However, at a pace of 1 m/s the energy cost of walking in donkeys (0.97 W/kg Lwt) was lower than in ponies (1.06 W/kg Lwt) and cattle (2.1 W/kg Lwt)

The results of these studies show that donkeys have two energetic advantages over cattle which may effect their ability to survive drought conditions.

1. Although the energy cost of standing per kg of live weight is higher in donkeys than cattle, the live weight of adult donkeys (150 – 200 kg) is much lower than of adult cattle (250 – 500 kg) kept by smallholder in sub-Saharan Africa . The daily maintenance requirements for energy of donkeys (18 – 24 MJ per day) are therefore much less than that of cattle (24 – 48 MJ per day); donkeys only need to consume around half the daily amount of net energy compared to cattle in order to survive.
2. The energy cost of walking in donkeys is about half that of cattle and as a consequence donkeys expend much less energy foraging than do cattle. A donkey that typically forages for 16 hours per day (Smith 1999) will expend approximately 26% less energy per kg of live weight than a cow that spends typically 10 hours per day foraging (Smith 1999); donkeys can spend longer looking for food than cattle because it costs them less energy to search.

Water requirements

Maloiy and Boarer (1971) carried out an experiment to compare the ability of donkeys and Zebu cattle to tolerate dehydration. These authors concluded that donkeys were only slightly more able to tolerate long-term water deprivation than Zebu cattle, having more controlled restoration of plasma osmolarity and better water conservation than cattle but otherwise having similar haematological changes. Maloiy and Boarer (1971) place donkeys nearer to cattle than camels in their ability to tolerate dehydration; similar to goats and sheep. In comparisons of the faecal dry matter content of water deprived African herbivores and their non-deprived conspecifics Maloiy *et al.* (1978) found that the biggest difference was in donkeys and camels, whilst there was little difference in cattle, goats and sheep. However, dry matter content of non-deprived sheep and goat faeces was higher than that of dehydrated donkeys. Maloiy (1970) concluded that Somali donkeys could tolerate loss of water corresponding to 30% of their body weight even at ambient temperatures of 40ºC and could restore the deficit by drinking 24-30 litres of water within 2-5 minutes. The Somali donkeys only had a limited ability to conserve water by increasing urine concentration, and the volume of urine was low (0.7 – 1.2 litres) even when water was freely available. Avenues of water conservation were through increase in faecal dry matter content and reduced evaporative losses. Appetite was maintained until 20 – 22% of initial live weight had been lost through dehydration (Maloiy 1970).

Yousef *et al.* (1970) induced short term dehydration in donkeys by exercising them (36 km walk – 10 hours) in the Nevada desert and observed that the animals ability to re-hydrated without over-hydration was similar that to that reported by Maloiy (1970).

Bullard *et al.* (1970) reporting haematological changes of donkeys states that there was little change in blood parameters during moderate dehydration (14 – 19% of initial live weight). Bullard *et al.* (1970) report that the maintenance of blood parameters during hydration is more similar to that seen in camels than is seen in Merino sheep.

Jones *et al.* (1989) and Sufit *et al.* (1985) induced thirst in donkeys and ponies in the absence of heat stress by overnight water deprivation, injection of diuretic and hyper-tonic saline infusion. Thirst responses in the two species were similar, although donkeys were slower than ponies to take their first drink when water was offered post-deprivation and did not over hydrate. Mueller and Houpt (1991) deprived donkeys and ponies of water under temperate conditions for a period of 36 hours and induced moderate dehydration and observed no significant differences in haematological parameters between species, however behavioural differences between species were significant. Water deprived ponies exhibited distress when they saw or smelt water, whereas donkeys did not. The food intake of water deprived ponies was depressed by over 30% but only 10% in donkeys. There were also significant differences in the water intake during the immediate 1.5 hours post-deprivation, water-deprived donkeys consumed almost the same amount of water in 1.5 hours as the controls had in the previous 36 hours; water-deprived ponies consumed 37% less water than their controls.

Dill *et al.* (1980) reported that fasted and water-deprived donkeys would choose hay before water when blood osmotic pressure had increased by 10% as a result of dehydration. When deprivation of water and food was increased so that blood osmotic pressure increased by 17%, donkeys would choose water rather than hay when given a free choice. Maloiy (1973) reported that water deprivation resulted in depression of food intake in Somali donkeys when their live weight losses resulting from dehydration had exceeded 15%, this was associated with an increase in apparent dry matter digestibility and faecal dry matter, suggesting a decrease in digesta retention time. Nengomasha *et al.* (1999) reported significant depression in food intake of poor quality hay in donkeys that were only given water at 48 and 72 hour intervals compared with those were given water *ad libitum*.

From these studies it appears that donkeys appear more able to tolerate thirst than ponies (Mueller and Houpt 1991, Jones *et al.* 1989, Sufit *et al.* 1985). Donkeys have been reported to be found grazing more than 24 hours away from their water source (Moehlman *et al.* 1998). Furthermore, dehydrated donkeys are more likely to choose food above water than dehydrated ponies (Dill *et al.* 1980). These responses to dehydration are behavioural rather than physiological. There are no published comparisons of the drinking behaviour of water deprived donkeys with that of cattle although rangeland studies of cattle and donkeys with free access to water in Zimbabwe showed that donkeys spend 25% less time at the water trough than cattle (Smith 1999).

Greater ability to tolerate thirst, re-hydrate rapidly and maintain appetite may give donkeys a survival advantage during times of drought over less thirst-tolerant animals. Areas close to watering points tend to be severely overgrazed in times of drought with the threshold of the grazing limit often been clearly observable by the change in vegetation density (Thrash and Derry 1999). If donkeys are more thirst tolerant than cattle, even to a small degree, this may give them access to relatively under-utilised areas of rangeland.

Ability to withstand dehydration and tolerate thirst should not be equated with an overall lower water requirement. Donkeys require as frequent access to water as any other type of livestock; donkeys that had free access to water drank more than those that only had access every 48 or 72 hours (Nengomasha *et al.* 1999).

Nutritional Factors

Standard texts on donkey nutrition give conflicting estimates of the voluntary dry matter intake of donkeys. McCarthy (1989) estimates daily dry matter intakes (DMI) of between 1.75 – 2.25% of body weight, whilst Fielding and Krause (1998) estimate daily DMI of between 2.5 – 3% of body weight. Standard estimates of daily DMI in cattle are 2.5 % (MAFF 1985). The estimate of Fielding and Krause (1998) concurs with the evolutionary conjecture of Janis (1976) who predicted that equids would generally have a higher intake of a given forage than cattle, relative to body size.

A summary of studies of the voluntary DMI of donkeys is shown in Table 2, along with the voluntary DMI of other livestock species included in the same studies. The mean DMI of donkeys based on these trails ranges between 0.9 – 2.5% of live weight, less than cattle (range 1.3 –3.3% live weight) and ponies (range 1.2 – 3.9% live weight) but more similar to that of sheep (range 0.7 – 2.6 % live weight) (Table 2). This analysis of published results concurs with the recommendations of McCarthy (1989) and contradicts those of Fielding and Krause (1998).

Based on the studies listed in Table 2, there is a significant relationship in cattle (r^2 =0.62 $p < 0.01$) between DMI and diet quality index (crude protein per unit of neutral detergent fibre), in ponies this relationship is less strong and not significant (r^2 =0.28), but in donkeys the relationship is very weak (r^2 =0.08). In practise this means that donkeys and to a less extent ponies are able to maintain intakes of poor quality forages which would cause a depression of food intake in cattle. In some respects this concurs with Janis's (1976) postulated equid feeding strategy which predicted a smaller effect of poor quality forages on intake in equids than cattle. However, Janis (1976) predicted generally higher intakes of forages in equids compared to cattle, in the case of donkeys this is not evident from the publish data. The analysis of published results presented in this paper supports this postulate for ponies but not for donkeys. This indicates that the two equid species have different feeding strategies from one another undermining the widely held view, supported by McCarthy (1989), that feeding standards for donkeys should be based on those for small horses.

The ability of donkeys to maintain DMI when feed quality is low is also support by studies of free ranging animals. Smith (1999) reported that donkeys kept under rangeland conditions in Zimbabwe maintain a similar level of DMI in both the wet and dry season (85 and 90 g/kg $M^{0.75}$ respectively) whilst cattle had much lower DMI in the dry season (69 g/kg $M^{0.75}$) that during the wet season (93 g/kg $M^{0.75}$). These measurements cannot be compared directly with those in Table 2 because of the indirect methods used to measure DMI.

There is considerable variation in mean retention time (MRT) between studies with animals fed similar diets (Table 3). For example alfalfa fed to maintenance by Cuddeford *et al.* (1995) was retained for 34 hours longer in donkeys and 43 hours longer in ponies than alfalfa fed *ad libitum* to the same experimental animals by Pearson *et al* (2001). The very long MRT of alfalfa fed to maintenance to donkeys and ponies during the study of Cuddeford *et al.* (1995) may been a result of the very small quantity of alfalfa required to satisfy their maintenance requirements. When these outlaying data points are removed from the analysis, MRT of particles is reduced to 45 and 40 hours in donkeys and ponies respectively.

The consensus on the effect of food quality on MRT in donkeys, for all but the Cuddeford *et al.* (1995) study (which was confounded by the low bulk of the diet), is that MRT decreases with an increase in food quality; to a similar extent to ponies and cattle (Table 3). The effect of food intake on MRT is not clear from the collated data. The only experiment to directly measure the effect of gut load on MRT in donkeys and ponies was reported by Pearson *et al*. (2001). In this experiment, increased intake reduced MRT in both donkeys and ponies (Table 3). The MRT of donkeys appears to show less variation (41 – 53 hours) than that of cattle (38 – 55 hours) fed similar diets *ad libitum*, but more than that of ponies (43 – 51 hours; Smith 1999). Again this result indicates that they are important differences between the feeding strategies of donkeys, cattle and ponies.

Few published studies have compared the differences between the dry matter digestibility of feed by donkeys and cattle. Smith (1999) reported more similarity between the dry matter digestibilities (DMD) of donkeys and cattle fed alfalfa, haylage and barley straw than between that seen in donkeys and ponies (Table 4). Other studies that compared DMD in donkeys with that of ponies have consistently shown that donkeys have a higher DMD of a given diet. As diet quality decreased the difference between the two equid species became more pronounced (Table 4).

The feeding strategy of donkeys appears to be distinct from both that of cattle and ponies. Donkeys maintain a low level intake of dry matter relative to their body size, more similar to sheep than either cattle or ponies. This level of intake is relatively independent of diet quality. Donkeys have MRT that are intermediate to that of cattle and ponies, but maintain DMD that are similar to cattle. In terms of drought survival this strategy may give donkeys an advantage over cattle in that they have a low DMI requirement, which they can maintain when feed quality is low, but donkeys are as efficient at extracting nutrients as cattle.

Foraging behaviour factors

The foraging strategies of the indigenous breeds of African cattle can be considered to be close to those of the wild bovids of the continent. In evolutionary terms, the slow moving, wild bovids were thought to have developed rumination as an anti-predation strategy, with exposure-time to danger being minimised during grazing by postponement of comminution (Kingdon 1997, Janis 1976). As the hunting activity of the major predators (lion, leopard and hyena) of large African bovids is largely confined to nocturnal periods (Haltenorth and Diller 1988), the avoidance of grazing during the hours of darkness may be a part of this anti-predation strategy.

Many workers (Harker *et al.* 1956, Lampkin and Quarterman 1958, Smith 1999) have recorded little night-grazing by indigenous breeds of African cattle under free ranging conditions; night-grazing activity seldom represented more than 5% of the total time available for grazing. Smith (1959) and Wilson (1961) reported that night-grazing by African zebu breeds kept in paddocks could occupy up to 4 hours of the night-time activity, particularly during the dry season when forage was in short supply. However, this was atypical and 2 hours per night was more normal. Smith (1961) also reported a mean grazing times of 2.2 hours between 18:00h and 07:00h by indigenous breeds of African cattle under free-range conditions, although not all of this observation period would have been during the hours of darkness.

The wild ass (Equus africanus), the ancestor of the domesticated donkey (Equus asinus), evolved in the semi-desert grasslands of Northeast Africa, preferring rocky hills to sandy areas (Kingdon 1997). Its foraging strategy was distinct from that of the other equids described by Janis (1976), although it is still predominantly a grazer rather than a browser (Haltenorth and Diller 1988). The wild ass is mostly a nocturnal grazer, spending most of the daylight hours resting (Haltenorth and Diller 1988).

The foraging strategy of donkeys also departs from that of the generalised equid strategy proposed by Janis (1976) in terms of the type of material selected from swards. Janis (1976) suggested that equidae tend to select stalk rather than leaf (i.e. select for fibre), based on the observations of Burchell's zebra (*Equus burchelli*) and wildebeest (*Connochates taurinus*) by Bell (1969); the equid selected more stem material than the ruminant. The results from the Smith's (1999) study show that donkeys do not conform to the strategy proposed by Janis (1976). Penned-animal trials (Smith 1999) also showed that donkeys and ponies are more selective than cattle; the equids selected against the bitter tasting leaves of alfalfa to a greater degree than cattle.

Donkeys spent a greater proportion of their day grazing than cattle. In particular, the hours of darkness were utilised extensively for grazing; a maximum of 17 h grazing per 24 h were recorded in the wet season during a study in Zimbabwean study (Smith 1999). The increased grazing time resulted in a greater nutrient intake in terms of both quantity and quality of food eaten. Donkeys consume a higher quality diet than cattle when grazing the same forage resource (Smith 1999).

From the limited number of studies that have been conducted, the feeding preferences of the domesticated donkey appear similar to those of its wild ancestor; browse being of secondary importance to grass in the diet (Pearson and Nengomasha 1994, Rudman 1990, Moehlman *et al. 19*98).

The foraging behaviour of donkeys may give they three advantages over cattle in drought survival:.

1. Donkeys are able to select a diet which is of better quality than cattle from the same area of rangeland.
2. Donkeys spend longer foraging during the day which gives them more time to find food of better quality.
3. Donkeys have a lower DMI requirement and therefore can more easily satisfy this requirement with food of better quality.

Discussion

Donkeys have a range of physiological and behavioural adaptations that individually may only provide small survival advantages over cattle, but collectively may make a large difference to whether or not they survive drought. These biological factors are enhanced by anthropomorphic factors which result in lower more sustainable populations of donkeys in sub-Saharan Africa.

Donkeys have lower maintenance costs as a result of their size, and spend less energy whilst foraging for food; lower energy costs result in a lower DMI requirement. In the donkey fermentation takes place in the hindgut and rate of passage is not restricted by food particle size as it is in ruminants, as a consequence donkeys can maintain food intake even when diet quality is low.

In donkeys low quality diets are digested almost as efficiently as in ruminants, and because of a highly selective feeding strategy, diet quality obtained by donkeys is higher on a given pasture than that consumed by cattle. Lower energy costs of walking, longer foraging times per day and ability to tolerate thirst allow donkeys to access more remote, under utilised sources of forage that are inaccessible to cattle.

The foraging strategy of donkeys is distinct from that of cattle; grazing management must reflect these differences. In particular, restricting time of access to grazing has a greater effect than it does on cattle; in donkeys restricting access to grazing to less than 12-hours results in a depression of DMI (Smith 1999). This is particularly important when donkeys are used as working animals. Typical working times for donkeys in Zimbabwe are between 3 and 6-hours per day (Nengomasha 1997) and frequently grazing is the only source of forage. Under traditional African grazing systems that only permit foraging during daylight hours, nutrient intake of donkeys will be adversely affected by both a decrease in the amount of DM consumed and a reduction in the quality of the ingested forage. Allowing donkeys to night-graze would compensate for loss of eating time during daylight hours. However, unsupervised night-grazing of donkeys can cause damage to crops. Often this proves detrimental to both human and animal welfare; when caught, marauding donkeys are often brutally killed or injured by farmers.

Fenced night paddocks, or effective barriers around crops would allow donkeys to graze unsupervised at night, but the cost of fencing is prohibitive. Providing a limited amount of poor quality, supplementary fodder in the kraal at night would provide a sustainable method of compensating for the loss of feeding time. Donkeys that are closer to satiety select a better quality diet than when hungry, and would, therefore, make more efficient use of any communal feed resources. The amount of supplementary fodder offered to each animal should be limited, to ensure that they are still motivated to feed at grazing and that the majority of the dietary DM would still be obtained there.

Providing small amounts of concentrate feed (0.3–0.5 kg per animal) would probably have a more beneficial effect than supplementary fodder. However, whether this is a viable option for poor farmers in developing countries is questionable. By-products from small-scale on-farm crop processing and kitchen waste could possibly fulfil this role, although donkeys would have to compete with meat-producing livestock, such as goats, for this resource.

The nutritional cost/benefit of providing fodder or concentrate supplements to donkeys with restricted access to grazing is clearer than it is for cattle. Donkeys with less than 12-hour grazing time have lower DMI than those with free access to grazing, regardless of forage availability or quality (Smith 1999). Donkeys are seldom used for anything other than to provide power and the benefit of sustained work may not outweigh the costs both in terms of effort and lost productivity by other classes of livestock. Where and when possible, the most economic option would be to provide donkeys with night grazing.

As donkeys become a more popular choice of working animal for farmers, specific management practices need to be devised that allow donkeys to fully maximise their natural survival advantages. Further research on the nutrient requirements of donkeys of donkeys is required in order that these management practices can be based on scientific principles rather than application of scaled-down feeding standards devised for horses.

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Table 1: Population ('000 head) of donkeys, cattle and small ruminants in Zimbabwe from 1977 to1995 and Ethiopia from 1997 to 1992.

	Zimbabwe			Ethiopia		
Year	**Donkeys**	**Cattle**	**Small Ruminants**	**Donkeys**	**Cattle**	**Small Ruminants**
1977	93	6,614	2,516	3,865	25,655	40,200
1978	94	6,027	2,649	3,870	25,864	40,270
1979	94	5,569	1,935	3,885	25,900	40,350
1980	95	5,279	1,369	3,890	26,000	40,430
1981	95	5,286	1,712	4,000	26,100	40,500
1982	96	5,662	1,320	4,100	26,200	40,570
1983	96	5,547	1,480	4,295	27,000	41,990
1984	97	5,465	1,938	4,400	26,000	40,350
1985	98	5,499	2,193	4,500	28,000	40,100
1986	99	5,783	2,498	4,600	30,000	40,000
1987	100	5,918	2,729	4,700	27,000	42,000
1988	101	5,820	2,988	4,800	27,000	42,000
1989	102	5,846	2,907	4,900	28,900	42,000
1990	103	6,407	3,139	5,000	30,000	40,160
1991	104	5,349	3,038	5,100	30,000	41,000
1992	104	6,024	3,034	5,200	31,000	41,300
1993	103	4,180	2,920			
1994	104	4,300	3,030			
1995	105	4,500	3,102			

Table 2. Neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (CP) and voluntary dry matter intake of donkeys, cattle, ponies, sheep and goats measured in comparative studies

	g/kg DM			Voluntary Dry Matter Intake (g per kg $M^{0.75}$)					
Diet	NDF	ADF	CP	Donkey	Cattle	Pony	Sheep	Goat	Source
Meadow hay	695	411	56	92	77				Butterworth 1985
Oat straw	708	485	25	77			64		
Teff straw	752	496	30	74			51		
Vetch hay	605	356	2	96					
Stylo hay	605	520	2	79					
Wheat straw	771	484	28	62				16	Izraely *et al.* 1989
Alfalfa hay	475	319	225	85				47	
Good quality grass hay	533	334	139	85					Mueller *et al.* 1984
Wheat straw	827	519	38	39					
Grass and Legume Hay	616	423	155	72					
Grass hay	662	414	74	67					
Millet stover and concentrates	785	521	36	60					
Millet stover	805	538	31	77					
Zimbabwean hay	780	460	60	75					Nengomasha *et al.* 1999
Alfalfa and cocksfoot hay	514		171	85			63		Ouedraogo and Tisserand 1996
Pasture hay	665		92	82			50		
Molassed wheat straw	466		31	60			30		

Table 2 (cont…). Neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (CP) and voluntary dry matter intake of donkeys, cattle, ponies, sheep and goats measured in comparative studies

	g/kg DM			Voluntary Dry Matter Intake (g per kg $M^{0.75}$)					
Diet	NDF	ADF	CP	Donkey	Cattle	Pony	Sheep	Goat	Source
Alfalfa	379	278	175	74	130	122	104		Pearson (unpublished)
Meadow hay	650	384	59	82	95	89	68		
Meadow hay	792	450	61	81	96	80	58		
Straw	834	537	24	52	50	52	35		
Alfalfa	443	339	146	100		155			Pearson *et al.* 2001
Oat Straw	715	487	39	60		95			
Hay	737	435	63	81		99			Pearson and Merritt 1991
Barley straw	886	567	31	37		60			
Haylage	656	392	98	60	75	61			Smith 1999
Alfalfa	382	288	198	67	104	78			
Barley straw	824	529	28	46	55	47			
Zimbabwean hay	785	497	30	52	53				
Mean DMI (g/kg $M^{0.75}$)				71.0	81.6	85.2	58.1	31.7	
s.e.				3.36	9.00	8.06	7.23	15.64	
N				29	9	11	9	2	
Mean DMI (% of live weight)				1.8	2.1	2.1	1.5	0.8	
Range of DMI (% live weight)				0.9 - 2.5	1.3 - 3.3	1.2 - 3.9	0.7 - 2.6	0.4 - 1.2	

Table 3. Feeding regime, neutral detergent fibre (NDF) content of diet and mean retention time of particles in donkeys, cattle and ponies in published comparative studies

		NDF	MRT (hours)			
Diet	Feeding regime	g/kg DM	Donkey	Cattle	Pony	Source
Alfalfa	Fed to maintenance	401	76.7		63.7	Cuddeford *et al.* 1995
Alfalfa (67%), Oat Straw (33%)	Fed to maintenance	459	59.2		50.4	
Alfalfa (33%), Oat Straw (67%)	Fed to maintenance	523	55.3		51.5	
Oat straw	Fed to maintenance	621	53.8		51.3	
Wheat straw	*ad lib*	771	38			Izraely *et al.* 1989
Alfalfa hay	*ad lib*	475	36			
Zimbabwean hay	*ad lib*	780	74			Nengomasha *et al.* 1999
Alfalfa	*ad lib*	443	33		21	Pearson et al. 2001
Oat Straw	*ad lib*	715	44		32	
Alfalfa	0.7 *ad lib*	443	40		31	
Oat Straw	0.7 *ad lib*	715	38		36	
Hay	*ad lib*	737	38		30	Pearson and Merritt 1991
Barley straw	*ad lib*	886	53		35	
Haylage	*ad lib*	656	52	47	49	Smith 1999
Alfalfa	*ad lib*	382	41	38	43	
Barley straw	*ad lib*	824	53	55	51	
Mean MRT (h)			49.1	46.5	41.8	
s.e.			3.3	5.0	3.3	

Table 4. Dry matter digestibility of diets fed to donkeys, cattle, ponies and sheep in published comparative studies

	Dry Matter Digestibility				
Diet	Donkey	Cattle	Pony	Sheep	Source
Alfalfa	0.67		0.68		Cuddeford *et al.* 1995
Alfalfa (67%), Oat Straw (33%)	0.62		0.58		
Alfalfa (33%), Oat Straw (67%)	0.56		0.55		
Oat straw	0.48		0.50		
Meadow hay	0.51			0.61	Butterworth 1985
Oat straw	0.49			0.52	
Teff straw	0.46			0.45	
Vetch hay	0.47				
Stylo hay	0.51				
Zimbabwean hay	0.41				Nengomasha *et al.* 1999
Good quality alfalfa and cocksfoot hay	0.60				Ouedraogo and Tisserand 1996
Poor quality meadow hay	0.53				
Molassed wheat straw	0.56				
Alfalfa (*ad lib*)	0.63		0.58		Pearson *et al.* 2001
Oat Straw (*ad lib*)	0.50		0.43		
Alfalfa (0.7 *ad lib*)	0.66		0.58		
Oat Straw (0.7 *ad lib*)	0.43		0.40		
Hay	0.54		0.49		Pearson and Merritt 1991
Barley straw	0.47		0.43		
Haylage	0.54	0.57	0.52		Smith 1999
Alfalfa	0.73	0.72	0.75		
Barley straw	0.53	0.52	0.44		
Good quality alfalfa and cocksfoot hay	0.63		0.58		Tisserand et al.. (1991)
Poor quality alfalfa and cocksfoot hay	0.53		0.51		
Straw, corn and soya cake	0.57		0.53		
Straw and corn	0.72		0.55		
Molassed wheat straw	0.56		0.53		
Mean DMD	0.55	0.60	0.53	0.53	
s.e.	0.02	0.06	0.02	0.05	
Number of studies	22	3	13	3	

Figure 1. Rainfall (mm) and annual change in donkey, cattle and small ruminant population (%) in Zimbabwe from 1978 to 1995

Figure 2. Rainfall (mm) and annual change in donkey, cattle and small ruminant population (%) in Ethiopia from 1978 to 1992