THE ROLE OF THE ANIMAL IN SOIL FERTILITY

(Met opsomming in Afrikaans)

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Introduction

Any investigation into the part played by the animal in influencing soil fertility, must of necessity extract data from a wide field of disciplines in applied science. One of the most fruitful approaches to such an investigation is that based on the concept of the ecosystem (Odum, 1963) which involves the consideration of both living and nonliving facets of the natural environment. Basically the system is made up of the inert edaphic and atmospheric factors which carry a population of living organisms grouped into three classes, namely (i) producers (ii) consumers and (iii) decomposers. In this context, the grazing animal is a consumer in a system made up of plants (producers) and micro-organisms and insects (decomposers).

In studying the animal as a consumer within a 'natural' ecosystem (eg on veld) or within an 'agronomic' ecosystem (eg mixed farming), the animal's energy budget may be defined as $I = Pg + Pr + E + M$ where I = calorific value of feed intake, Pg = production through growth, Pr = production through reproduction, M = metabolic heat loss and E = calorific value of excretion, defecation and secretion. (Van Dyne, 1969).

Whereas this review is primarily concerned with the domestic animals, a more balanced and more efficient ecosystem is often attained when a variety of animals is included in the system. It has been shown by Talbot & Swift (1966) for instance, that whereas the *Acacia* savannah of Kenya can support only 2 000 kg of cattle, sheep and goats per square kilometre, the same veld is capable of supporting between 12 000 and 18 000 kg of mixed game.

It can be argued that if animal production is to be profitable, then the animals' total contribution to the fertility of its feed-producing unit must be negative, ie a gross removal of elements must take place. In this regard it should be noted however that (a) a large proportion of the N in animal dung consists of bacterial cells (b) that re-cycling of nutrients by the animal for continuous re-use is more important than the level of fertility as such and (c) that certain patterns of defoliation and loosening of the soil surface by animals' hooves have a stimulating effect on the growth of pasture plants.

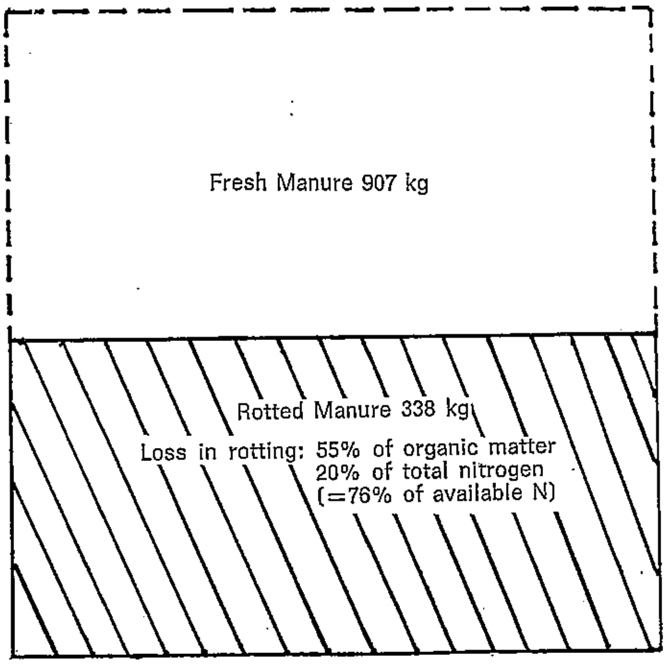

Fig 1 Losses from farmyard manure stored under cover for three months (Worthen & Aldrich, 1956)

Factors affecting the animals' contribution to soil fertility

The quantitative effects of the animal on the soil fertility of a given area, will be determined firstly by the number of animals per unit area, secondly by the composition, intake and digestibility of the feed consumed, and thirdly by the time spent by the animals on the area concerned. Each of these factors is in turn influenced by a number of basic determinants, which are beyond the scope of this review.

Having reached the soil surface, the nutrients and organic matter in the excreta of animals may be susceptible to considerable losses due to (i) volatilization (ii) removal in surface runoff (iii) use by insects and (iv) removal by humans for fuel.

The use which is made by plants of that proportion of excreta which does enter the soil, may in turn be influenced by (i) leaching by rain (ii) fixing of minerals (iii) limiting temperature and moisture conditions as well as by (iv) the depth of rooting and density of the plant cover. In this regard it should be stressed that the animal, when used as an agency of poor management on natural vegetation, has a decidedly negative effect on soil fertility. This occurs when over-utilization results in destruction of plant cover leading to higher runoff and severe loss of soil. Figure 1 indicates the losses from stored manure.

Inherent soil fertility as modified by animal excreta

The animals' contribution to soil fertility can only be properly evaluated in relation to the inherent level of fertility in the soil, as derived from the earth's crust through soil genesis. Using dolerite (ironstone) as an example of a common soil-forming rock in South Africa, it is found that the rock consists of 52 per cent silica and only small proportions of plant nutrients such as K (0,81%) and P (0,08%) while N is absent. The soils derived from dolerite vary widely in their nutrient status, depending on the environment in which they have formed. Doleritic soil on the Natal coast for instance, has a pH of 5,8 and contains 0,10%K, 0,04% P and 0,17% N, the latter presumably originating mainly from rainfall (Malherbe, 1964). Total nutrient content of the soil is however misleading as seen from the fact that although 150 mm of topsoil may contain 370 kg P (0,04% dry) per hectare, a crop such as wheat will only utilize 2 kg of this, as shown by the fact that 14,5 kg P (180 kg superphosphate) is necessary to obtain a yield of over 400 kg per hectare. A wheat crop of 10 bags per hectare requires 5 kg per hectare (Malherbe, 1964).

In general terms a soil containing less than 0,05% N and 0,02% P may be regarded as poor under South African conditions, while a fertile soil contains in excess of 0,2% N and 0,1% P. Thus although 80 per cent of the atmosphere consists of N (7 million metric tons N/square kilometre of the earth's surface) this vital plant nutrient is in short supply and under the circumstances, the value of animal excreta becomes clear. Table 1 indicates the relative nutritive value of various South African manures.

TABLE 1 Analyses of South African manures (Malherbe, 1964) (% on dry basis)

	Organic matter	Ash	N	P	K
Kraal manure (WP grain farms)	56	44	2,2	0,5	1,4
Karoo manure (sheep farms)	50	50	1,6	0,6	2,5
Kraal manure (summer rainfall area)	53	47	1,6	0,3	1,4

The N in animal dung occurs mainly in two forms; firstly as residual protein which has not been broken down in the digestion process and secondly as proteins that have been synthesized in bacterial bodies. More than half the excreted protein may be in the latter form and since this form is readily broken down in the soil, this N is very largely available to plants. Up to one third of the dry matter in dung may consist of bacterial cells. The dung also contains large amounts of lignin (plant fibre) which forms soil humus and releases N slowly into the soil.

Urine on the other hand contains those nutrients which have been digested and 'used' by the animal body. All the nutrients in urine are soluble and directly available or readily become available to plants. Urine thus differs from dung in the availability of its nutrients as well as in its low P and high N and K contents. The more digestible the animal feed, the higher is the proportion of nutrients found in the urine. When excreted, the N in urine is largely in the form of urea and hippuric and uric acids. These compounds are not volatile but organisms in the excreta rapidly break down these compounds to ammonia, which combines with water and carbon dioxide to give ammonium carbonate. This is unstable and may lose virtually all its ammonia on drying, causing great losses of N

$$(NH_4)_2CO_3 \longrightarrow 2NH_3 + H_2O + CO_2.$$

Qualified data on nutrients in animal excreta

Many workers have determined the nutrient content and the mass of manure and urine voided by different classes of livestock. Clearly, these figures are very variable, but approximated figures are useful for comparative purposes. Data of Miller, Turk & Foth (1965) are summarized in Table 2.

It is important to note that the above figures represent approximately 75 per cent of the intake of the major nutrients and organic matter. Approximated utilization of nutrients by livestock is given in diagrammatic form in Figure 2.

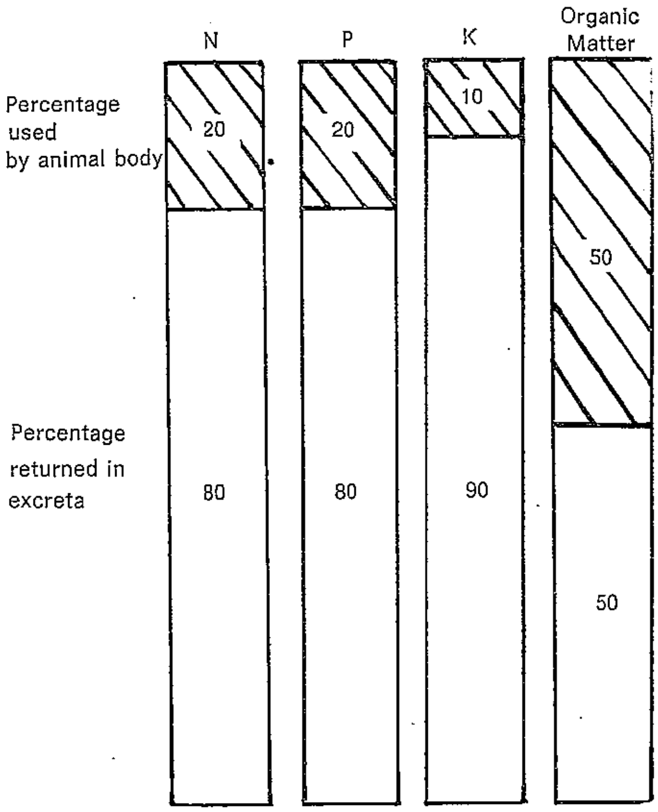

Fig 2 Proportion of nutrients in feed, used and returned to the soil by farm animals (Millar, Turk & Foth, 1965)

TABLE 2 Nutrient content and annual production of animal excreta (Millar, Turk & Forth, 1965)

Animal	Excrement	H_2O %	N kg	P kg	K kg	Tonnes/450 kg live-mass/year
Horse	dung		2,5	trace	2,3	
	urine		4,0	1,0	2,4	
	total	78	6,5	1,0	4,7	8,2
Cow	dung		2,1	trace	3,1	
	urine		2,2	0,5	0,5	
	total	86	4,5	0,5	3,6	12,2
Pig	dung		1,8	0,15	1,4	
	urine		1,6	1,2	1,8	
	total	87	3,5	1,4	3,1	13,9
Sheep	dung		4,5	0,06	5,2	
	urine		4,9	1,3	2,3	
	total	68	9,4	1,4	7,5	5,7
Poultry	Total	55	9,1	3,2	3,6	3,9

Nutrient cycling under intensive farming conditions

Data on the nutrient content of excreta become more meaningful when compared with the absolute amounts of nutrients removed from the soil by crops used for feeding livestock. Malherbe (1964) reports such figures, and Table 3 indicates the nutrient removal by two of South Africa's most important fodder crops, namely lucerne and maize.

TABLE 3 Removal of nutrients by crops (Malherbe, 1964) (kg/ha)

Crop	Yield	N	P	K	Ca
Lucerne (hay)	6,4 t/ha	166	18	32	214
Maize (whole plant)	1,86 t grain 2,65 t stover	30 20	5 1,5	5 32	35 14

The nutrient balance sheet is made more complete by calculating the actual amounts of nutrients removed when animals and animal products are sold off the production unit concerned. While the absolute quantities of nutrients removed will be directly influenced by stocking rates, Sears (1950) offers a useful basis for the calculation of nutrients removed based on meat and milk production per unit area as shown in Table 4.

TABLE 4 Removal of nutrients in animal products (Sears, 1950) (kg/ha/annum)

Product	Ammonium sulphate equivalent	Superphosphate equivalent	Lime equivalent	K salts equivalent
6 745 l milk/ha (sold)	180	67	23	33
1 120 kg beef/ha (sold)	130	86	45	6
7 sheep/hectare fattened to 68 kg (sold)	117	54	24	54

The writer (Roberts, 1959) has shown that in the use of irrigated grass/clover pastures in the central Orange Free State, grazed by dairy cows, a total of 1 590 dung pats is deposited on a hectare of pasture annually, when rotational strip-grazing is applied. This is equivalent to 65 kg ammonium sulphate and to approximately 122 kg ammonium sulphate when the urine is added. Normal & Green (1958) have demonstrated that compared with the average crude protein content of a given pasture sward (13,3% CP), herbage within a 600 mm radius of dung pats and urine areas contain 14,8% CP and 16,5% CP respectively. In such excreta areas the yield of herbage is raised from 3 700 kg DM per hectare to 5 800 kg near dung pats and to 3 900 kg near urine areas. Wheeler (1958) demonstrated a further effect of excreta on pastures, namely the influence on botanical composition. It was shown that urine was the dominant factor leading to species changes in intensively grazed swards.

The role of the animal in soil fertility maintenance is by no means limited to the nutrient content of its excreta, but should also be evaluated in terms of the general ameliorating effects of the organic matter voided. Russel (1963) sums the matter up when he states "Soil tilth has often been described as something every farmer can recognize but no scientist can describe". This healthy condition of the soil combines chemical, physical and microbial fertility and has been recognized since earliest times as the old saying goes "Lime and lime without manure, will make both farm and farmer poor".

Under South African conditions however, high temperatures result in relatively rapid breakdown of organic matter, making it necessary to apply farmyard manure at the rate of 20-40 tonnes per hectare for good results. It is estimated that 1,6 million tonnes of manure is applied to ploughed lands in South Africa annually (Malherbe, 1964).

Thus although animal dung and urine require to be properly handled to prevent losses during collection, storage and application, their value to the production system may be very great. Sears (1950) has shown that the fertilizer equivalents of excreta voided on grass/clover pastures to be 3 000 kg ammonium sulphate, 760 kg superphosphate, 300 kg lime and 2 094 kg potassium salts per hectare per annum.

A nitrogen balance sheet under veld grazing conditions

It is possible to evaluate the total annual contribution of animals in South Africa to fertility by calculating the amounts of excreta voided by the animal population as a whole and converting this to commercial fertilizer units at current prices.

On a regional basis, the potential contribution by animals to fertility is directly proportional to (a) the carrying capacity of the veld in extensive farming regions and (b) the level of fodder production in intensive farming regions. It has been shown that carrying capacity of the veld is almost linearly related to annual rainfall in the inland areas of the western half of South Africa (Van den Berg, 1970) and data is available on the digestibility of veld grazing in most regions (Van Niekerk, 1967). Approximate herbage yields and nutrient yields per unit area can be estimated from carrying-capacity figures, mass gains and daily nutrient requirements (Garrett, 1959). It has been shown for instance, that in the central Orange Free State, the veld can produce an average of 280 kg TDN per hectare annually (or 18,3 kg live-mass) when grazed at one beast per 4,3 hectare, over a period of 11 years (Mostert, Voster & Donaldson, 1964). Cattle and sheep excrete about 40 per cent of their intake from veld. Most types of grassveld in South Africa yield between one and 2,5 tonnes DM per hectare annually. A steer of 270 kg requires about 4 kg TDN per day and this is supplied by about 30 kg fresh grass. Both the protein content and the yield of grassveld may be increased by fertilizing with nitrogen and Meredith (1948) has shown that annual live-mass gains can be increased from 70 kg per hectare to 220 kg by fertilizing sourveld. It has also been found that the TDN yield of veld may be increased from 644 kg to 1 700 kg per hectare per annum by nitrogen fertilizing.

By estimating the amount of nitrogen available per unit area in veld grazing and subtracting from this the proportion retained by the animal, it may be calculated from the number of animals per unit area, what quantity of nitrogen is returned to the soil for re-cycling in the ecosystem. The most significant local contribution to this field of study is that of Gillard (1963), carried out at Frankenwald near Johannesburg.

Gillard states that while Erikson (1952) has shown that the amount of nitrogen added to the soil annually by rainfall in North America and Europe is 7,5 kg and 8,1 kg N/ha respectively, the figure measured at Bapsfontein in the Transvaal is between 11 kg and 17 kg per hectare. Since mineralization of N is very low under grass, loss by leaching is negligible (Theron, 1963).

Gillard showed that N retention is not higher than 20 per cent in beef animals, and usually nearer 15 per cent. It was found that the cattle at Frankenwald defaecated twelve times and urinated eight times per day on average, as was found by Petersen (1956) and Harker (1960). Each dung pat covered about 650 square centimetres while urinations (600 ml) each covered 2 600 square centimetres. Applying these data to a 200-day grazing season, the proportion of the pasture on which excreta was voided, was calculated for the four stocking rates used, as set out in Table 5.

TABLE 5 Area of veld covered by excreta at four stocking rates (Gillard, 1963)

Stocking rate (LSU/ha)	Percentage of pasture covered per annum
1	7,4
2	14,1
3	25,6
4	36,8

It can be seen that with heavy stocking, virtually the entire area of veld will have been covered by excreta within three seasons. However, since high stocking rates can only be obtained when fertilizer is applied, a high nitrogen turnover cannot otherwise be obtained.

With a moisture content of 80 per cent and an N content of 2 per cent, Gillard found that by the time dung had dried on the veld, it had lost more than two-thirds of its original nitrogen. It was found that dung beetles (eight genera) buried virtually all dung within five days of being voided, spreading the dung to twice its original area in the process, and affecting a fertilizer treatment equivalent to approximately 430 kg N per hectare on such dung areas. Soil analyses indicated that the action of the beetles reduced N losses from about 80 per cent to 10 per cent. Since the animals concerned voided about 16 kg N per season in dung and only 3,7 kg N in urine (0,27% N) the beetles' action is of great importance in the nitrogen economy, and it is for this reason that Australia, which has no indigenous dung beetles, is presently introducing South African beetles.

Urine N is lost from the soil surface which is fertilized at the rate of 63 kg N per hectare where the urine falls, but Gillard indicates that the loss after three weeks amounts to only 2 per cent of the total N in the urine, although up to 24 per cent may be lost from urine remaining on the grass tufts and not reaching the soil.

The grassveld on the South African Highveld yields about 21 kg N/ha per year in its herbage when dominated by *Trachypogon* and 32 kg N/ha when dominated by *Eragrostis* and *Cynodon* (Fisher, 1958). It has also been shown (Leigh, 1960), that recovery of applied fertilizer nitrogen by veld is 50 per cent or less and Gillard's investigations indicate that the recovery of excretal N is 25 per cent in the first season and 20 per cent in the second season, thus a total recovery of 45 per cent (as also obtained elsewhere) was assumed as a basis for N economy calculations. An increased rate of N turnover in the ecosystem results in a higher overall production due to the increased number of times that the same 'nutrient capital' is re-cycled per season. The Frankenwald trials yielded comparative data on the amount and rate of cycling of nitrogen under veld grazing conditions over a range of stocking rates. These data are shown in Table 6, in which the known data for N in live-mass, N in grazed herbage and N in excreta are compared.

TABLE 6 Nitrogen economy of veld grazed at two stocking rates (Gillard, 1963)

	Low stocking (6 LSU on 6,8 ha)	High stocking (6 LSU on 3,4 ha)
N retention in live-mass	2,7 kg N (at 20% retention)	4,5 kg N (at 15% retention)
Excreta	10,9 kg N	24,1 kg N
Herbage grazed	9,5 kg	28,6 kg
Recovered excretal N	5,0 kg	10,4 kg
Mineralized N	18,2 kg	18,2 kg

It may be seen from the above table that high stocking rate leads to a more efficient N economy. Gillard however points out that this arrangement is not stable and leads to an increase in subclimax grasses at the expense of climax species.

Considering the nitrogen balance sheet in the grazed veld situation, it was found that the addition of N to the system through symbiotic fixation by legumes was absent and that the total gain of N through rainfall and free living N-fixing organisms was 16-21 kg N/hectare per annum. The N retention by beef steers is between 8 per cent and 20 per cent, which means that 3-5 kg N is removed from climax *(Trachypogon)* veld and 5-8 kg N from sub-climax *(Eragrostis-Cynodon)* veld. It was shown that despite this loss, soil analyses indicated no lowering of the soil N status after nine years of very intensive grazing, ie despite the removal of an average of 47 kg N/hectare over this period. An important effect of heavy stocking is the prevention of immobilization of nutrients in unconsumed grass and this fertility change encourages sub-climax grasses which, in the case of the Highveld are highly resistant to defoliation and yield well. Gillard concludes that even heavier live-mass gains may be obtained after heavy grazing has caused the sub-climax grasses to dominate. When extreme grazing pressure is applied, the limiting factor is not soil N but growth vigour, as reduced by too frequent defoliation.

Conclusion

Considering that South Africa's population has increased by 86 per cent since 1936 and that agricultural production has increased by 125 per cent during the same period, the local food-supply position may be considered to be satisfactory at present. With a daily consumption of 2 800 calories per person per day for all races, South Africa maintains a diet which is enjoyed by only 20 per cent of the world's population. However, with an annual loss of topsoil equivalent to 55 000 hectares (300 mm deep), containing major plant nutrients to the value of R6-50 per hectare, (a national loss of R790 million) the importance of efficient return on animal excreta on a country-wide basis becomes very important. Animal production from pastures contributes approximately 30 per cent of total agricultural production and is valued at R390 million. Since the area of fertile arable soils is one of the primary limiting factors in South African agriculture, the sooner local agriculturists learn to appreciate the contribution which animals can make to soil productivity once excreta are handled properly, the sooner stability of our wasting natural resources will be achieved.

Opsomming

DIE ROL VAN DIE DIER IN GRONDVRUGBAARHEID

Die bydrae van die dier tot grondvrugbaarheid moet gesien word binne die raamwerk van die breë voedingstofsiklus. Die dier (as verbruiker) speel 'n belangrike rol in die sirkulasie van voedingstowwe wat deur die plant (as produsent) beskikbaar gestel word. Die mikro-organismes (ontbinders) se funksie is om die uitgeskeide materiaal om te sit in vorms wat vir plante weer beskikbaar is.

Die omgewingsfaktore bepaal primêr hoeveel energie (plantmateriaal) beskikbaar is vir gebruik deur die dier en dus vir sirkulasie in die ekosisteem as geheel. Die mis en urine van plaasdiere is onderhewig aan baie hoë verliese aan stikstof, en kraalmis moet dus reg behandel word. Syfers is beskikbaar tov die totale voedingstof en inhoud van diereuitskeidings, asook tov die voedingstowwe wat deur voergewasse uit die grond opgeneem word. In die beweidingssituasie op natuurlike veld, is dit bewys dat, mits stikstof nie beperkend is nie, 'n hoë veebelading kan lei tot 'n meer doeltreffende stikstofsirkulasie in die ekosisteem onder hoë reënval toestande.

Die invloed van mis en urine word nie tot chemiese vrugbaarheid beperk nie, maar sluit ook in grond struktuur, botaniese samestelling en die algemene mikrobiese gesteldheid van die grond.

Omdat die hoeveelheid vrugbare grond wat beskikbaar is, 'n beperkende faktor in die Suid-Afrikaanse landbouproduksie is, is dit nodig dat meer doeltreffende gebruik gemaak word van die dier as faktor in die handhawing en verhoging van grondvrugbaarheid in hierdie land.

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Discussion

Dr Möhr

I have two questions. How important is the mechanical distributon of excreta on pastures under intensive grazing? My second question has to do with the loss of plant nutrients by soil erosion. According to American data, losses of nutrients other than nitrogen are very high. Could Prof Roberts comment on the fact that the losses from nitrogen are not very high?

Prof Roberts

Is the low loss of nitrogen proportional or is it in fact because there is such a little nitrogen to begin with? I understand that the leaching of nitrogen under a permanent grass cover is very low. As soon as the grass cover is denuded or the biological life together with the roots are destroyed, then the situation changes and the nitrogen does leach faster than in the case of ploughed lands — particularly during the period when the crop is on the land.

Regarding the distribution of excreta, I believe that this is something which we shall have to study on a large scale in this country. We shall have to learn how to distribute excreta effectively on high-producing pastures. The question is largely one of pasture management and better utilization of the pasture. Cows for example do not come back in the following grazing to those areas where droppings and urine have fallen, but we have found that they do come back to such areas after irrigation. However the mechanical spreading of dungpats possibly results in a greater loss of nitrogen through volatilization.

Mr E B Dickinson

Is there likely to be any variation in efficiency of the animal in nitrogen economy in different grazing systems? For instance, is a multi-camp grazing system likely to be better than say a four-camp system?

Prof Roberts

I don't think we have the answer to this, and that is why I appeal for more work on the lines of Gillard's work.

We certainly know that with a more flexible multi-camp approach where one has a shorter grazing period and a longer rest — simply giving nature more opportunity to produce, particularly in the sweet veld — one finds a greater total production. I can't say to what degree this greater production is a result of better physiological growth conditions or to nitrogen economy. With smaller camps and more intensive grazing one would perhaps have a higher concentration of nitrogen during the grazing periods. Under favourable conditions one might expect a more efficient recovery of nitrogen, using the multi-camp approach, but we don't really know. What should be done is to follow this up under different grazing systems much on the same lines as Gillard has done.