CASE STUDY OF ADAPTIVE RANGELAND MANAGEMENT BY AN INNOVATIVE KALAHARI FARMER

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ABSTRACT

Scientists can learn a great deal from innovative farmers who apply adaptive management principles based on experience gained over decades. This paper records 31 observations that a farmer, Jan Labuschagne, made on his farm to the south of Gobabis. The observations relate to aspects such as animal behaviour and performance, animal trampling, and applications of grazing and fire. They are tabulated together with their possible explanations and their management applications. The conceptual model the farmer has built to aid his understanding and decision making is also shown as a diagram and explained. Of critical importance is the strategic timing of management interventions on different parts of the farm in relation to rainfall events, texture and organic content of the soil and maturity of the vegetation. Data are presented to support some of the observations.

INTRODUCTION

Rangeland experimentation is costly, laborious and occupies large tracts of land (Edwards, 1969). Experimental research alone cannot produce a rigid rangeland management formula because of the infinite combinations of variables that would need to be tested and the complexity of rangeland dynamics that interplays with those variables (Stuart-Hill, 1989). However, many experienced farmers are continuously experimenting and monitoring on their farms, albeit in a subjective manner, and then adjusting their management styles accordingly. Stuart-Hill (1989) regards this adaptive approach as the solution to rangeland management, coupled with input from formal research, preferably on-farm research. Norton (2003) is of the opinion that scientists cannot duplicate the success of commercial producers who are proving that rotational grazing "works" both biologically and financially.

One such adaptive farmer, Jan Labuschagne, has achieved remarkable results with his rangeland. He was willing to share what he has learnt and to reveal how he has adapted his management techniques. His farm Weiveld (23.06° S, 18.88° E) in the Omaheke region of Namibia shows fence-line contrasts with the neighbours. The farm covers about 3 000 ha in the Camelthorn savanna (Giess, 1971), dominated in the herbaceous layer by *Stipagrostis uniplumis*, in the bush layer by *Acacia mellifera* and *Grewia flava*, and in the tree layer by *Acacia erioloba*. The farm falls within the agroecological zone known as Kalahari Sands Plateau AE2 (De Pauw, Coetzee, Calitz, Beukes & Vits, 1999) dominated by ferralic arenosol with low stabilised dunes and some petric calcisol with pans. The clay content over most of the farm varies between 3 % and 8 %. Rainfall is highly erratic with a long-term annual mean of roughly 250 mm, occurring only in summer. Annual evaporation is about 2 m, with an average maximum temperature of about 33 °C in the hottest month and an average minimum of about 2 °C in the coldest month (Mendelsohn, Jarvis, Roberts & Robertson, 2002). Stocking rates vary according to rainfall and market prices. When the study commenced in 2004, the farmer had about 230 cattle and 1 300 sheep on his farm, giving an overall stocking rate of about 7 ha/LSU (assuming 6 sheep/LSU). On the neighbouring farm, the overall stocking rate was about 14 ha/LSU.

According to the farmer, his management objective is to improve both grass and animal production in a balanced way. He states that the improved production should be sustainable and that the result should be the maximum level of production that can be supported by the landscape and its climate. The fluctuating nature of the latter implies that the maximum production potential would also fluctuate from year to year.

The farmer inherited from his father not only the farm, but also a large loan since the farm was still mortgaged. In order to repay the inherited loan, the farmer was forced to stock the farm excessively during the first few years. He observed the resultant degradation on the farm, but could only afford the luxury of adaptive management once he had paid off the loan. Thereafter he was able to convert his observations into some degree of experimentation through trial and error and apply adaptive management principles. Since soil water is an extremely limiting factor in this environment, many of the farmer's observations were based on the depth to which soil remained moist at different times after rain, and on the ways in which different types of soil responded to different management influences. He got into the habit of carrying a spade with him whenever he travelled around the farm in order to dig holes at different sites to investigate the soil water profiles.

METHODS

The farmer and one of his neighbours were interviewed by means of a formal questionnaire. Questions included those aimed at understanding the management styles applied to the farms and others aimed at quantifying the production levels achieved. Because certain answers were regarded as of critical importance, they were further explored during and after the interviews. The farmer made a drawing of his conceptual model, which was then copied. He was accompanied on visits to various sites on the farm, where he showed the effects of different management techniques and described the observations that had led him to experiment with various strategies.

Measurements of vegetation were made on each side of fence-line contrasts, one on the farm boundary of the neighbour who was interviewed and others internally within Weiveld. The measurements were made along four 250 m transects or two 500 m transects on each side of the fence and parallel to the fence, starting 30 m from the fence and 40 m apart. Grasses were recorded from 25 or 50 points per transect, giving 100 points on each side of the fence, which Zimmermann, Joubert & Graz (2001) have found sufficient to smooth the running mean. The points along the various transects were spaced roughly 10 m apart through a combination of uniform pacing and a randomly thrown dart. The observer paced about 8 m, turned 180° and threw a dart roughly 2 m over his shoulder in the direction of the transect. At each point along the transects, where the dart landed, the numbers of perennial grasses and bushes shorter than 0,5 m were counted within 0,75 m of the point. When the longer term condition of the rangeland was being evaluated, only the perennial grasses with a basal diameter of 5 cm or more were counted, but when evaluating the short-term effect of a management intervention, all perennial grasses were counted. At each fourth point, giving 25 points on each side of the fence, the overall canopy cover of trees and bushes taller than 0,5 m was measured by a Bitterlich gauge (Friedel & Chewings, 1988) using a half angle of 12°55′. The clumped distribution of some bushes made it difficult to determine where the canopy of one plant ended and another began. Therefore, in cases where canopies in a clump overlapped to form an approximate circle, the whole clump was counted as one individual, even if the canopy of each individual bush did not extend beyond the sighting pins of the Bitterlich gauge. Such a clump was therefore treated as if it were one large canopy instead of many smaller canopies.

RESULTS

The farmer's observations

Tables 1 to 4 list observations made by the farmer, possible explanations given by the farmer for the observations, and the management actions the farmer took in view of the observations. The 31 observations have been broken down into four groupings, each shown in a separate table.

Table 1. Observations related to animal behaviour and performance, and their conversion to management applications

Observation of farmer	Possible explanation given by farmer	Management application
1.1 When few cattle are sent ahead of the main herd rotation, they grow quickly and consume less phosphate lick per animal.	The greater availability of forage per animal allows them to select higher-quality food.	Lower the stocking rate to improve animal performance and reduce lick costs, while leaving more grass to feed soil microorganisms.
1.2 If urea lick is withdrawn, cattle stop feeding on moribund grass material and old mulch.	Urea provides nitrogen needed by rumen microflora to digest the high carbon/low nitrogen moribund material.	Stop using urea lick, leaving moribund grass to be trampled onto the soil to supply important humus (and save costs).
1.3 If less phosphate lick is provided to cattle, they do more browsing.	Browse leaves have higher phosphate content than grasses.	Provide less phosphate lick, to help control bush encroachment and save costs.
1.4 Animals prefer grasses growing under bushes to those growing in the open.	Bushes improve mineral status of soil under their canopies and their shade reduces evaporation from the soil.	Maintain a good balance between bushes and grasses. Do not try to eradicate any bush species.
1.5. If artificial breeding seasons are discontinued, then cattle do not simply breed all year round.	Cattle naturally adhere to two breeding seasons, one in winter and one in summer.	Keep bulls with the herd throughout the year. Not only is this simpler to manage, but it allows rangeland to rest for longer and be grazed for shorter periods, owing to a higher number of paddocks per herd.
1.6 Dung beetles die after livestock have been dosed against intestinal worms.	The dosing chemical makes its way into the dung which is still toxic when dung beetles feed on it.	Stop dosing livestock against internal parasites. Rather disrupt parasite life cycles by rotating livestock through paddocks, and build up natural livestock resistance by providing sufficient, good-quality forage.
1.7 Livestock stop feeding for a few days at the start of the rainy season, after which they only feed on green flush and no longer on dry material.	Livestock anticipate the advent of a green flush and allow the microflora in the rumen some time to adapt from dry to green feed.	Lower the stocking rate and allow livestock to feed on newly established annual grasses and forbs. The animals then move further afield, trampling uneaten dry grass into mulch and raising levels of organic matter in the soil.

1.8 Smaller breeds of cattle perform better in this environment than larger breeds.	Smaller cattle breeds and small stock are better adapted to this environment than larger breeds of cattle. Larger animals need to spend more time feeding.	Change breed of cattle from Brahman to Nguni or Beefmaster, and also farm with sheep and goats. However, actual breed is less important than fertility within the herd.
1.9 Sheep prefer to follow cattle in the grazing rotation, but goats prefer to go ahead.	Sheep prefer feeding on grass after cattle have grazed and shortened it, but goats face increased tannin content in browse leaves, in response to previous browsing by cattle.	No solution applied yet, because it is logistically difficult to separate out goats and send them up ahead.

Table 2. Observations related to animal trampling, and their conversion to management applications

Observation of farmer	Possible explanation given by farmer	Management application
2.1 At the start of the rainy season, much of the annual grass, *Schmidtia kalahariensis*, grows on the side of a fence recently trampled by sheep, but not on the other side which has not been trampled recently.	Grasses such as *S. kalahariensis* germinate better if their seeds are covered by soil blown into hoof marks.	Make use of sheep trampling as a rangeland management tool.
2.2 In the occasional year when cattle are disturbed by small biting flies (possibly stable flies), the cattle push themselves into bushes of *Grewia flava*, and grass subsequently flourishes under those bushes.	The trampling by cattle creates hoof marks in which grass seeds are trapped. Later they are covered by some soil and mulch. The hoof marks also encourage water infiltration during the rains that follow.	Use cattle trampling as a rangeland management tool.
2.3 Trampling of soil low in organic matter results in the weed *Tribulus terrestris* and encourages the establishment of bush seedlings, while trampling of soil with sufficient organic matter results in an abundance of grass after rain.	Soil low in organic matter becomes hotter than soil with sufficient organic matter. Grass seeds cannot survive or germinate successfully in hot soil, while seeds of *Tribulus terrestris* and bush species can.	Only allow a lot of trampling where the organic content of the soil is high or there is enough standing dry grass to trample down into the mulch layer.
2.4 Trampling of sandy soil in the dry season does not increase subsequent perennial grass density, while trampling it in the growing season does, if followed by rest.	Trampling in the dry season loosens the soil around grass roots, so that they become desiccated or uprooted. If the soil is moist, it is not loosened so easily and hoof marks remain fairly firm.	Only apply trampling to sandy soil in the growing season (if soil organic content is sufficient).
2.5 Trampling of loamy soil containing low organic matter when it is moist causes hardening of the soil.	Because moist loamy soil cannot resist trampling pressure, it becomes compacted. If hard and dry, it resists compaction.	Reduce the stocking rate on loamy soil in the growing season.
2.6 Trampling before rain falls on loamy soil improves water infiltration and the establishment of grass seedlings.	Trampling causes hoof marks; seeds and mulch settle into them before rains and they hold water after rains.	Apply brief trampling before rain to capture more rainwater, seeds and mulch.
2.7 Trampling after it has rained on soil containing sufficient organic matter conserves the water already present in the soil. If low in organic matter, the loosened soil dries out fast.	Trampling breaks the capillary connections in the soil surface, thereby reducing capillary rise of water after evaporation of soil water from near the surface.	To reduce evaporation loss from the soil, allow brief trampling after good rains, provided the soil contains sufficient organic matter.
2.8 Trampling after good rains on soil where few perennial grasses grow tends to favour bush growth.	Bushes use the soil water conserved by the trampling since there are insufficient grasses to use it.	Rather trample such poor paddocks after the first rain of the season, to encourage perennial grass emergence.
2.9 Damara and Van Rooi sheep provide a better trampling service on hard ground than Dorper sheep.	Damara and Van Rooi sheep have sharper hooves than Dorper and have retained their herding and mothering instincts better.	Farm mainly with Damara and Van Rooi sheep, mixed with limited Dorper genes to provide the larger animals demanded by the market.
2.10 The presence of a few jackals causes sheep to remain bunched together, which provides a better trampling service.	Sheep feel more secure in the presence of jackals when bunched together. Therefore, they create a higher density of hoof marks.	Control jackals to a limited extent and sacrifice the loss of a few sheep, so that the herd bunches well and mothering instincts continue to be selected for.

Table 3. Observations that convert to applications of grazing, wood harvesting and farm design

Observation of farmer	Possible explanation given by farmer	Management application
3.1 When stocking rate is increased slightly, young plants are badly damaged while middle-aged plants recover more easily.	Plants are more sensitive or resistant to being eaten or trampled as they go through different stages of their life cycles.	Adjust the rate of rotation through a paddock depending on the life cycle stage of its dominant plants.
3. 2 If senescing perennial grasses are grazed or trampled, they tend to rejuvenate, competing with new grass seedlings, and do not produce sufficient mulch or forage of good quality.	Removal of old grass parts allows buds to obtain sufficient sunlight and air for continued growth.	Rest a paddock dominated by senescing grasses for longer (effectively lowering the stocking rate) to allow the grasses to be converted into mulch later on and to encourage the establishment of new grass seedlings.
3. 3 Mole mounds often appear in the rainy season where bulls have fought. Moles do not appear where rangeland was rested for the full growing season.	Moles prefer to burrow in moister soil. Fighting bulls conserve soil water by loosening topsoil, which breaks capillary connections with the moist subsoil. Rangeland rested in the growing season loses more water.	Mole mounds can be used as an indicator of higher soil water. If grasses dominate, then conserve the water by trampling. If bushes dominate, then it is not a priority to conserve water.
3. 4 The condition of perennial grass is much better in a small paddock, compared to that in a neighbouring large paddock, despite being grazed at the same stocking rate.	The much shorter grazing period and slightly longer rest received by the small paddock safeguard the perennial grasses against overgrazing. However, if a paddock is too small, then the crowding of animals restricts them from selecting better grass.	Subdivide large paddocks to improve perennial grass cover (down to the most economically efficient size of about 100 ha for this agroecological zone, or down to the most functionally efficient size of 50 ha if moveable electric fencing is available).
3. 5 After a drought, animals like to graze in areas dominated by annual grasses.	When drought breaks, annual grasses grow quickly, while perennial grasses take a long time to provide forage.	Keep a good balance between paddocks dominated by perennial and annual grasses to benefit from both.
3. 6 When mature *Acacia mellifera* bushes are harvested for droppers, they are replaced by seedlings only if chopped during a year of good rains and not during drought.	Mature *A. mellifera* bushes suppress seedlings unless weakened, such as by chopping. Seeds of *A. mellifera* do not remain viable for long and their seedlings die easily unless sufficient follow-up rains fall.	If it is necessary to treat the symptoms of excess mature *A. mellifera*, it should be done in dry years. Prevention, by treating the cause, is better than cure if applied early enough.
3. 7 Runoff rainwater tends to soak into the ground on a certain part of the farm.	There might be deeper soil or cracks in the layer of calcrete.	Align roads to bring their runoff rainwater to this area, to recharge the aquifer.

Table 4. Observations that convert to applications of fire

Observation of farmer	Possible explanation given by farmer	Management application
4.1 After years of exceptionally high rainfall, perennial grass starts to regenerate in spring, before new rain has fallen.	Sufficient soil water from the previous rainy season remains in the soil, allowing grass to regrow in response to rising temperatures.	Only apply the tool of fire after exceptionally high rainfall, so that the risk of damaging perennial grass is lowered. Even if there is little or no rainfall after the fire, the grass will be able to rely on stored soil water.
4. 2 During years of exceptionally high rainfall, much more grass grows than can be consumed by the livestock, which will cause the cost of renting land to drop.	The higher soil water content allows grass to grow throughout the growing season, but livestock does not reproduce at the same rate. As the supply of forage increases, the demand decreases and hence the price of forage drops.	After a year of exceptionally high rainfall, restrict livestock to only part of the farm, or place livestock on rented land during the entire dry season so that sufficient fuel remains at the end of the dry season to apply fire in some of the rested paddocks.
4. 3 If rest is provided after many animals have grazed a paddock with a high cover of *Acacia mellifera* bushes, then many annual grasses establish under the bushes after the next rain.	Animals like to feed on fallen leaves under the bushes, where they provide a trampling service that favours subsequent grass establishment.	Apply trampling especially during the season before wanting to apply fire to increase the fuel load underneath excessive bushes.

4. 4 Annual grass burns better than perennial grass in the dry season.	Annual grass has more leafy material and less water in the dry season.	Allow trampling to encourage annual grass germination at the start of the growing season before fire is applied.
4. 5 Many *Acacia mellifera* bushes produce seeds after years of exceptionally high rainfall.	Conditions of moderate or low rainfall do not provide enough water for *A. mellifera* to produce pods.	Apply fire to kill the pods when they are abundant (where sufficient fuel and soil water have accumulated).
4. 6 Animals prefer to feed on grasses growing under taller bushes with wide canopies than on grasses growing in the open.	Bushes improve the mineral status of soil under them and their shade reduces evaporation from the soil.	Before applying fire to a paddock, send in a few cattle to reduce and trample fuel under large bushes in order to minimise fire damage to those valuable bushes.

Conceptual model

The farmer has developed a conceptual model to explain the basics of rangeland dynamics and assist him with his decision making on rangeland management (Figure 1). The condition of the rangeland in any paddock is shown in the model by two variables. Distance from the centre of the circles represents the state or successional stage of the rangeland in the paddock, shown in Figure 1 as three concentric circles. The inner, middle and outer circles represent rangeland dominated by annual plants, perennial grasses, and woody plants respectively. For rate of rotation, Figure 1 should not be viewed as a clock, with the arm performing equal revolutions regardless of distance from the centre. The closer to the centre, the faster the rotation.

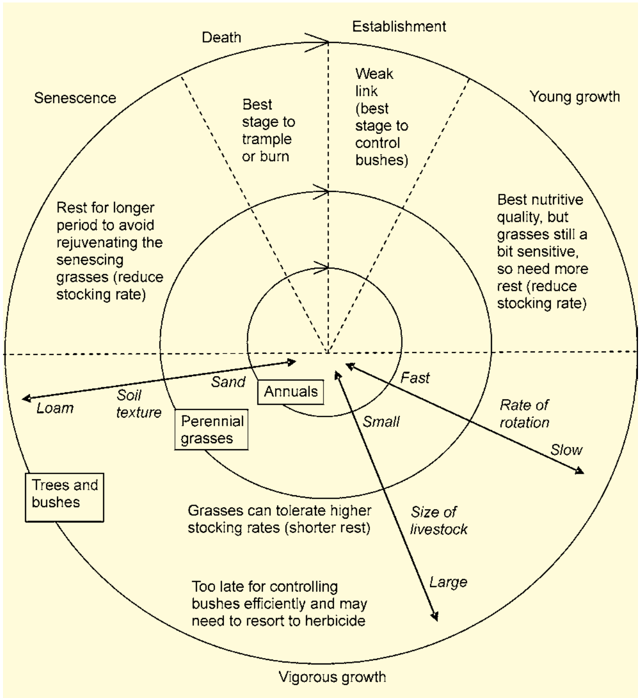

Figure 1. Conceptual model developed by Jan Labuschagne to explain rangeland dynamics on his farm, Weiveld.

The position of rotation represents the life cycle stage of the dominant vegetation in the paddock starting at 12 o'clock in Figure 1. Annual plants have the shortest life cycles lasting one growing season, whereas perennial grasses have life cycles of several years or decades, and woody plants have life cycles of several decades or centuries. Therefore, in the conceptual model, the rate of one revolution is fast for the inner circle, but slows down as the circles progress outwards. The five stages of a life cycle are labelled outside of the outer circle, although they apply to both perennial grasses and woody plants.

Some management implications applicable to different stages of the life cycle have been inserted between the outer and middle circles in Figure 1. The two double-ended arrows on the right show management implications that change according to the types of plants dominating the forage intake, although they apply to all life cycle stages and not only to the vigorous growth stage where they were drawn because space was limited. The double-ended arrow on the left shows the influence of soil texture on the type of plants generally favoured there.

When annual plants that do not need a long rest dominate forage intake, a rapid rate of rotation through paddocks enables stock to optimise the "fast food" while it lasts. Sandier soils favour such conditions and small stock thrives on them. When animals graze more on perennial grasses that require moderate rest, the rate of rotation should be slowed down. Such conditions, usually on soils of intermediate texture, favour moderate-sized stock. Browsed trees and bushes need longer rest, so rotation should be slowed down even further if the browse is more important to the farmer. Larger animals tend to perform well under such conditions, which are favoured on more loamy soils.

Management principles currently applied

At present, the farmer applies many of the principles that he has identified through his adaptive management approach. He farms with sheep, goats and cattle of small frame. In paddocks that have jackal-proof fencing, the cattle and small stock are combined. The overall stocking rate is adjusted so that sufficient grass material remains to be trampled into the soil at a later stage. The rate of rotation through paddocks depends on the season.

In the growing season, all the livestock are combined into one large herd that is rotated quickly, which means spending only 3 to 14 days in a paddock. By the end of the growing season, each paddock has usually been grazed twice. The time that the animals spend in any paddock depends largely on the condition of its rangeland, and is shorter if the dominant perennial grasses are senescing or just establishing, and longer if the grasses are middle-aged. After heavy rains, the rate of rotation is speeded up to ensure that the capillaries at the soil surface are broken, thereby reducing evaporation loss of water from the soil. The sequence of rotation from paddock to paddock is not fixed, but is flexible in order to use opportunities as they present themselves. Some paddocks dominated by annual grasses are trampled after the first rain of the season to encourage establishment of perennial grass seedlings. The rate of rotation might be speeded up again at the end of the growing season to ensure hoofmarks over most of the farm with a view to trapping grass seeds and a mulch of leaves.

In the dry season, the animals are split into seven herds, and the rate of rotation is slowed down considerably. Each herd then rotates slowly through the three or four paddocks surrounding a single water point, grazing each paddock either once or twice during the long dry season of about eight months. No supplementary feed is provided, except on rare occasions when the condition of livestock suffers because of exceptionally late rains. Then twigs of the evergreen tree, *Boscia albitrunca*, are milled and mixed with phosphate lick.

The farmer no longer imposes breeding seasons on the livestock, but allows the animals to settle into their own breeding seasons and to give birth out on the rangeland. None of the livestock is kept in kraals at night, so the animals learn to care for themselves, while their dung and urine redistribute mineral nutrients all over the rangeland rather than concentrating them at the kraals. The farmer even tolerates low predator densities to retain mothering instincts of his livestock and benefit from the trampling provided by the tighter bunching of his herd. He stopped supplementing his livestock with urea, so that moribund grass and mulch would no longer be eaten by the livestock but would feed the soil microorganisms instead. He largely stopped using chemical pesticides, and only doses newly acquired sheep before releasing them onto his farm. Apart from encouraging well-fed animals that are more resistant to parasites and avoiding parasite concentrations in kraals, control is largely achieved by adjusting the rate of livestock rotation. By allowing his livestock to graze a paddock for no more than 14 days in the growing season and resting the paddock for up to three months, the life cycle of parasites is broken. Useful organisms, such as dung beetles, started to increase noticeably about three years after the broad-scale use of chemicals had been discontinued.

Findings at fence-line contrasts

The perennial grass density was much higher on the strategically trampled farm Weiveld than on the neighbouring farm where conventional rotation was applied through four paddocks per herd (Figure 2). A similar trend was noticeable in the density of the palatable leguminous perennial forb, *Otoptera burchellii*, estimated at 2 150 plants/ha on Weiveld, compared to only 453 plants/ha on the neighbouring farm. On the other hand, the bush canopy cover was less on Weiveld, especially for *Acacia mellifera* (Figure 3).

All this attests to the better rangeland condition at the farm Weiveld, presumably owing to the good management principles being applied there, although historical mismanagement may also have contributed to the poorer condition of the neighbouring farm.

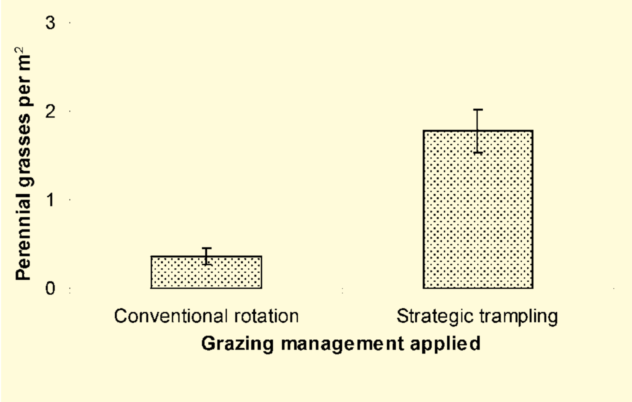

Figure 2. Densities of perennial grass plants of basal diameter greater than 5 cm on either side of the boundary fence between the farm Weiveld, managed by strategic trampling, and the neighbouring farm, managed conventionally. Error bars show ± 95 % confidence limits.

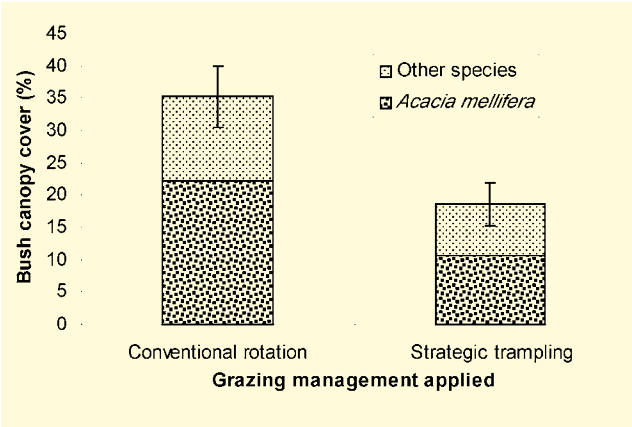

Figure 3. Canopy cover of bushes taller than 0,5 m, divided into *Acacia mellifera* and other species on either side of the boundary fence between the farm Weiveld, managed by strategic trampling, and the neighbouring farm, managed conventionally. Error bars show ± 95 % confidence limits.

A higher density of perennial grasses was evident on the side of the internal fence on the farm Weiveld, which had received brief trampling early in the growing season (Figure 4), presumably owing to the hoof action that buried seeds at that critical time of the year and supporting Observation 2.2. The reason why the perennial grass densities are higher in Figure 4 than in Figure 2 is that the latter only shows well-established perennial grasses of more than 5 cm diameter at the base, whereas Figure 4 shows all perennial grasses, including the young ones that established during the same season. Whether or not those young grasses survive depends on the follow-up rains.

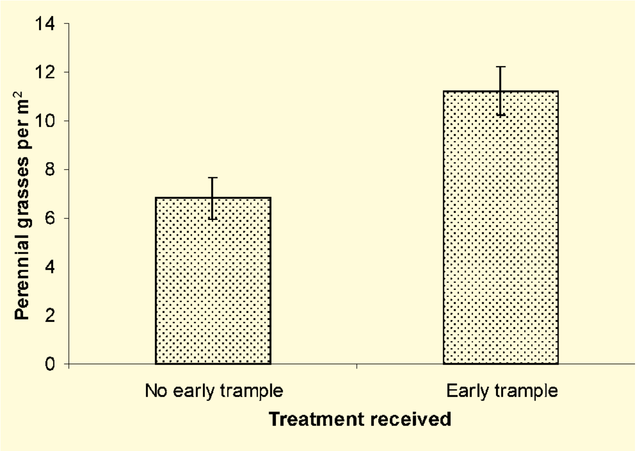

Figure 4. Mean densities of perennial grasses ± 95 % confidence limits on either side of an internal fence on the farm Weiveld, one side of which had been trampled for a few days by a large herd of livestock shortly after the first good rain of the season.

A small paddock of only 6 ha showed a higher density of perennial grasses than its two larger neighbouring paddocks, supporting Observation 3.4 (Figure 5). The density of small bushes lower than 0,5 m increased when the size of the paddock increased, ranging from an estimated 113 plants/ha in the 6 ha paddock, to 340 plants/ha in the 120 ha paddock, to 1 175 plants/ha in the 340 ha paddock. This suggests that bushes have established more readily in the larger paddocks because of the weakened state of perennial grasses growing in these paddocks.

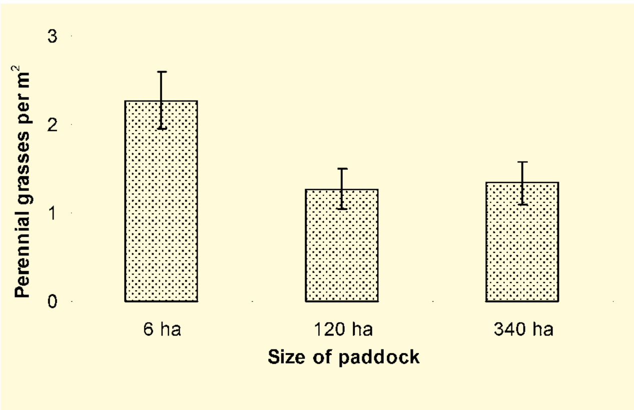

Figure 5. Mean densities ± 95 % confidence limits of perennial grasses of basal diameter greater than 5 cm on either side of internal fences on the farm Weiveld, separating paddocks of different sizes, which were grazed at similar stocking rates.

DISCUSSION

Management decisions need to take many factors into account and can therefore be extremely complex. Different options, such as those emanating from the observations in Tables 1 to 4, should be weighed up against each other, and decisions directed at the weak link in the production system. Management decisions concerning one part of the farm must take into account the situation on the other parts of the farm as well as expected seasonal changes. A farmer can usefully exploit the diversity of soils and vegetation on his/her farm (Scoones, 1995), for example, by using areas with sandy soil more often in the growing season and heavier textured soils more often in the dry season. Management interventions should also be timed precisely, especially in relation to rainfall events. For example, the optimum time to trample a paddock would depend not only on its predominant soil texture and organic content, but also on the balance between bushes and grasses growing there and their stages of maturity. Paddocks with few perennial grasses and many new bushes should therefore rather be trampled after the first good rains of the season to encourage the establishment of more grasses, while trampling after rains, later in the growing season, should be avoided to prevent conserved soil water from becoming more available to the young bushes.

Generally, stocking rate is recognised as a major management variable that influences the condition of rangeland and animal production (O'Reagain & Turner, 1992); however Tainton (1985) lamented the fact that stocking rate has received less attention from researchers than rotational grazing procedures. Observation 1.1 accounts for both improved animal performance and increased soil organic matter from lower stocking rates. Du Preez & Snyman (2003) confirm that soil organic matter declines with degradation of the rangeland, while Observation 1.2 suggests that withdrawal of urea lick may contribute to higher soil organic matter. Urea withdrawal may also improve animal performance by reducing high levels of blood urea nitrogen that put stress on the animals' livers (Brunetti, 2004), probably indicated by high urine pH. Some farmers measure the pH of cattle urine as an indicator of when to move their cattle to the next paddock or when to start or stop nitrogen supplementation (Schultheiss, 2005). However, this is not done at the farm Weiveld.

Observation 1.3 supports data tabulated by Moleele (1998), which show higher phosphate content in browse than in grasses found in southeast Botswana. Although cattle generally prefer grazing to browsing at the Sandveld Research Station (Rothauge, Smit & Abate, 2007), the extent to which they browse is sometimes considerable, as evidenced by Katjiua & Ward (2006). They found that cattle spent 71 % of feeding time browsing on bushes in a communal grazing area near Otjinene, where grass is less abundant. Observation 1.4 supports the findings of Rothauge *et al.* (2007) that grasses occurring in canopied habitats had a significantly higher nutritive value than those found in the open at the Sandveld Research Station, even if they were of the same species. This is borne out by Hagos & Smit (2005) who found that a gradient existed in soil nutrient status, ranging from higher near the stem of freestanding *Acacia mellifera* trees, to lower further away from the canopy in open ground. Observation 1.5, namely, that cattle naturally synchronise into two breeding seasons, may simply be a continuation of the momentum of the two artificial breeding seasons applied until four years previously, made possible by the low predator pressure on the calves. The calving seasons may continue to migrate slowly through the calendar year over a long period (perhaps decades), until they reunite at a single, ideal natural time of year if management practices allow this to happen (Ruechel, pers. comm.) A small possibility also exists that photoperiod influenced the calving seasons, since sexual activity and breeding tend to peak during the equinoxes (Ruechel, 2006), and current groups of calves appear to have been conceived near the time of the two equinoxes. However, the effect of photoperiod is less pronounced in tropical latitudes, where longer calving seasons tend to revolve around the cycles of the rainy/dry seasons (Ruechel, 2006).

Observation 1.6 should be noted because dung beetles perform essential services, not only by bringing nutrients, organic matter and beneficial microorganisms into the soil, but also by reducing the breeding opportunities for parasites and flies in dung that otherwise remains on the soil surface (Losey & Vaughan, 2006). Therefore, the toxic remedies used for control of both internal parasites (Kryger, Deshodt & Scholz, 2005) and external parasites (Chihiya, Gadzirayi & Mutandwa, 2006), which pose a danger to dung beetles, may have severe consequences for the health of both rangeland soils and animals. Fortunately, parasites can be controlled without the use of toxic chemicals – as is now done on the farm Weiveld – by rotational grazing to disrupt the parasite life cycle, selective breeding for greater resistance, and ensuring a good level of nutrition from a high diversity of forage species, which enhances resistance against parasites and diseases. Literature could not be found in support of Observation 1.7, namely, that animals stop feeding for a few days of transition from the dry season to the growing season. However, the rumen microflora would be slow to adapt to changes in diet, such as a sudden shift from dry grass to green material. Cattle need to acclimatise to lush spring growth after a season on dry feed, otherwise they may suffer from severe rumen upsets, laminitis, bloat, nitrate poisoning or even death (Conroy, 2007). If cattle do indeed stop feeding, it may be because of a physiological response to an upset rumen resulting from sudden intake of lush green material (Conroy, pers. comm.). Alternatively, cattle may prefer to wait for the fresh growth that they know will soon be available rather than continuing to feed on poor quality dry material, especially if the first rain leached the few remaining nutrients from it (Ruechel, pers. comm.). Observation 1.8 supports the findings of Els (2007) that small-frame cattle showed a higher production per hectare than large-frame cattle at comparable stocking rates at the Sandveld Research Station. The explanations given for observation 1.9 fit with findings of Bell (1971) that grazing by larger species breaks down stemmy grass swards, thereby exposing leafy material for smaller grazers, and with findings of Van Hoven (1991) that tannin content of leaves increases rapidly in response to browsing.

The observations in Figure 4 support the findings of Rotundo & Aguiar (2004) that sheep trampling doubled the emergence of *Bromus pictus* seedlings in Patagonia. They suggested trampling as a low-input technique for increasing grass recruitment. The use of trampling as a management tool is a contentious issue that has received much criticism. A review by Thurow (1991) indicated that trampling tends to result in lower infiltration rates where it destroys stable soil aggregates, and leads to a deterioration of soil structure. A review by Holechek, Gomes, Molinar, Galt & Valdez (2000) indicates that various studies on short-duration grazing consistently found increased erosion, compared to continuous or season-long grazing. However, the observations at farm Weiveld suggest that trampling could bring about benefits if applied at the right time under the right conditions, and if followed by sufficient rest in the growing season, for the rangeland plants to recover.

Dean (1992) found reduced water infiltration rates in sheep paths of Karoo soils, but the infiltration rate was higher where more organic matter and insect activity were found in the soil. Chaichiu, Saravi & Malekian (2003) found that sheep trampling reduced the water infiltration rate into soil. Such observations may be due to a lack of sufficient rest after the trampling, if not due to the soil conditions at the time of trampling, or to the duration and intensity of the trampling applied. An account by Howell (1976) of trampling applied by three South African farmers emphasised that timing is an important factor in trampling. While Savory (1999) seems to treat animal impact as a relatively simple tool, with variables of type of animal, stocking density and timing, observations at farm Weiveld suggest that trampling is more complex and that variables of season, soil texture, soil water profile and organic matter content of the soil should also be controlled for. Ssemakula (1983) shows results of hoof pressures measured for different species of ungulate. The observations on farm Weiveld suggest that species results should be differentiated even further, into breeds. An additional explanation for Observation 2.9, that Damara sheep provide a better trampling service, could be that they walk longer distances than other sheep (Conroy, pers. comm.).

Observations 3.1 and 3.2 contributed to the conceptual model in Figure 1 and are taken into account when decisions are made on grazing management. Observation 3.4 and Figure 5 show the advantage of smaller paddocks, but at higher cost. Booysen (1969) considered the upper limit of paddocks per herd to be about six, beyond which an increase in resting benefit is slight. At farm Weiveld, the paddocks per herd vary between 19, when the tool of trampling is applied in the growing season, and 3 in the dry season. Observation 3.6 supports the contention by Smit (1998) that competition from well-established bushes prevents new bushes from establishing within their root zones, which are extensive for species such as *Acacia mellifera*.

Burning, like trampling, is a contentious issue with a variety of pros and cons (Scott, 1970). Stehn (2008) doubts whether the use of fire as a management tool can be viably applied within a farming operation that has to care for itself financially, because of the removal of potential forage and the long rest needed both before and after the fire. However, if fire is applied only rarely, at opportune times, the benefits might outweigh the costs. According to Mr Labuschagne, a farmer should prepare for burning years in advance in order to build up the soil organic matter and the widespread cover of annual grass. Before burning, the farmer should be certain that there is sufficient water in the soil from the previous rainy season to ensure that perennial grasses will be able to regrow even if no rain should fall soon after the fire. Sufficient water will only be present in the soil after exceptional rainfall. This fortunately coincides with the occurrence of other situations that warrant the consideration of burning, namely when grass is likely to be abundant and when there is a risk of encroacher bushes establishing on a grand scale from seed (Joubert, Rothauge & Smit, 2008).

Observations related to the control of bush encroachment are scattered throughout Tables 1 to 4, at 1.3, 1.4, 2.8, 3.3, 3.6, 4.3 and 4.5, while Figure 1 shows some of their applications in the conceptual model. A healthy diversity of bushes and grasses is encouraged by good grazing management. However, if bushes of *Acacia mellifera*, the main encroacher species on farm Weiveld, show signs of becoming dominant, then they should be controlled while at their weakest, at the start of the life cycle (Joubert *et al*., 2008). This could start with the application of fire if masses of pods appear on the parent bushes and if sufficient fuel and soil water are present (Observation 4.5). However, the possibility exists that if not burnt, the seedlings emerging from the masses of seeds would die in any case from lack of follow-up rain, so it might be more economical to wait and reconsider the situation in the following season. Nevertheless, since only a portion of the farm should be burnt in any year, one or a few paddocks could be burnt if masses of *A. mellifera* pods were produced there. If follow-up rains are good and many bush seedlings establish in other paddocks, then the next opportunity to apply burning might occur at the end of the following dry season. Alternative burning of individual paddocks spaced apart on a farm could achieve the type of patch burning advocated by Fuhlendorf & Engle (2001).

CONCLUSIONS

Although no hard scientific conclusions can be drawn from rangeland experimentation unless all variables have been controlled for and assessed (Edwards, 1969), valuable lessons can be learned from the adaptive management style practised by this farmer. Other farmers can conduct similar experiments on their farms and any conclusions drawn could be followed up by scientific experimentation, if necessary.

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