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Feeding strategies to increase small ruminant production in dry environments☆

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Abstract

In the low-rainfall areas of much of Africa and Asia, small ruminants represent the principal economic output, contributing a large share of the income of farmers. Animal numbers have increased over the last two decades, driven by a rising demand for animal products and subsidized feed price (e.g. barley, maize). Side effects of this and changing climatic patterns are increasing desertification, resulting in a decline in rangeland resources, which are often insufficient to meet current demand, coupled with a fall in total feed resources due to overgrazing, ploughing of marginal land and soil erosion. Consequently, goats and sheep are facing serious nutrient shortages. These animals often depend on low quality crop residues (e.g. straws, stubbles) and expensive feed supplements. Technical solutions to some of these problems are available, for example the advantageous use of fodder trees, shrubs and cactus has been demonstrated. Conservation through ensiling and the use of feed blocks (FB) gives greater efficiency of use of a wide range of agro-industrial by-products (AGIBPs). But their adoption has been slow, often because of lack of knowledge of the farmers' problems and expectations. Adaptive research of technologies and management practices are needed, to provide the policy and institutional support for wider adoption of improved production and resource management practices. Some research–development projects based on the farmer participatory approach have resulted in improved crop and livestock technologies being introduced. On-farm surveys and in-depth economic analyses have shown that these pioneer projects have contributed significantly to the welfare of farmers in dry areas. The lesson learned from these projects is that "by working hand-in-hand with rural communities, agricultural researchers and extension specialists, it should be possible to refine and promote technologies and policies that might help ensure sustainable livelihoods and enhance the productive capacity of drylands everywhere". Success stories of technology transfer projects include the Mashreq and Maghreb project (International Center for Agricultural Research in the Dry Areas [ICARDA]-coordinated project).

Keywords: Small ruminants; Feeding strategies; Cereal crop residues; Agro-industrial by-products; Fodder shrubs; Dry environment; Technology adoption

1. Introduction

In the developing world livestock are the key to security for many smallholder farmers (Owen et al., 2004, 2005) and are often used as indicators of wealth. In the drier areas preferred species are goats and sheep, the ranking of the major outputs of milk, meat, fibre, manure and skins depending on local demand, including

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that of the household, and access to markets. Of necessity, the systems are low-input and productivity is low. Increased livestock production is invariably associated with an increase in livestock numbers, while the available land, because of human pressure for more cropping areas and infrastructural development, has gone down (Thomas and Rangnekar, 2004).

Areas of concern include: breeding (local breeds tend to be small and disease resistant, both desirable traits, but they are also low milkers and slow to grow), where crossbreeding is practised the larger progeny require better nutrition and more support to withstand local conditions; nutrition, often resulting from both an inadequate supply of forage and low quality (high fibre low/protein); diseases, including endo-parasitic burdens; management, embracing reproduction, housing and control of resources; access to credit and micro-finance, essential if necessary inputs such as feed supplements and drugs are to be purchased; readily available and relevant knowledge; market information; government decisions and policies adverse to the aspirations of the livestock producer. Most of the problems listed above will be exacerbated by extreme environmental conditions, especially drought but occasionally excessive rainfall resulting in flooding. The onset of drought is only clear through hindsight and its end unpredictable. Although meteorological predictions are still not a precise science and to be of practical relevance the information must be available to farmers, advisers and policy makers to allow forward planning and control of feed resources (or destocking before livestock prices collapse). Long-term steps to mitigate the effects of drought should include water harvesting, the development of drought tolerant crops and appropriate land tillage and livestock management procedures. Water harvesting should include collection of roof water, minimization of run-off and the cultivation of succulents as livestock feed as well as dam building.

Urban areas are affected by drought when dams and aquifers cannot meet demand. Because plants grow predominately in the upper layers of soil, they depend on expected patterns of rainfall; farmers with irrigation are cushioned against immediate effects of drought; those without irrigation, often smallholders, at or just above subsistence, are the most vulnerable group. Even with irrigation, farmers still like to cultivate some vegetables (e.g. pepper, tomato) or fruit trees (e.g. vineyard), which can result in a shortage of forage and the need to buy concentrates. Degradation of rangelands and the need to purchase feeds are pressurizing resource-poor smallholders dependent on small ruminants. This results in diversification within the farmer or of the younger family members, often the men, as itinerant urban workers. Because of the knowledge of small ruminant production of many of these people, it is desirable to stop this drift from the land by creating a profitable farming system (Peacock, 1996). A battery of technologies has been developed to improve the use of local feedstuffs; technical, institutional and policies options have been recommended to improve the small ruminant sector in the dry areas. In this paper potential techniques will be discussed.

2. Impacts of drought on the livestock sector

In drought prone areas keeping of small ruminants, rather than large species, has the advantage that more animals can be kept per unit of land thus spreading risk (six ewes are approximately equal to one cow). However, the use of large ruminants for transport and draught power, together with their emotive value, cannot be ignored. As ruminants, goats and sheep depend on forage as their primary source of feed. In the dry season the forage supply falls and that available is fibrous and low in protein. Unless the diet can be ameliorated growth rates and lactation will decline, to be followed by conception rates and birthweights—on the other hand abortion and mortality rates (especially of twin-born and newly weaned progeny) will increase. In extreme cases deaths, including those of adults, will also increase, resulting in an immediate loss of income until the numbers of breeding females recover (much faster with small compared to large ruminants due to their shorter generation interval).

An obvious first action for the livestock keeper as drought starts to bite is to destock. However, drought does not strike an individual and a consequence of it is the establishment of a buyers' market. A partial solution is to sell all non-breeding stock early in the drought when it is obvious that the season is abnormal but before the pressure on feed resources forces sales.

Government also has responsibilities in helping farmers survive drought: both to sustain food supplies for the urban population (buying imports should be seen as a last resort) and preventing resource-poor smallholders sliding into poverty. Adequate warning systems and market information should be freely available to producers. In extreme cases feed should be moved from areas of plenty to where it is needed at a subsidized rate. An alternative form of subsidy is on delivered product but the disadvantage of this is that stock retained for breeding would not benefit. The provision of credit through micro-finance schemes is essential, both for the purchase of inputs and restocking. 'Pass on the gift' schemes, run by several non-governmental organisations (NGOs) can also help with restocking and often supply some technical support for recipients.

Institutional and policy options are part of the armour for defeating drought and subsequent restocking (Heffernan et al., 2001; Morton and Barton, 2002), thus helping to preserve livestock production and the livelihoods of rural households. However, for the livestock keeper there are a number of technical and managerial options which can be used on the farm.

3. Technical options to alleviate the impact of drought on sheep and goat performance

Adequate testing of options to be recommended to farmers is essential. A combination of laboratory analysis, research-controlled and on-farm trials will be required, depending on the hypothesis to be tested. A checklist of the steps needed to carry out nutritional trials for livestock is available (Buttery et al., 2006). Laboratory analysis will probably include screening to select potential forage sources, either by the use of *in sacco* (nylon bag) or *in vitro* (gas production) techniques. Preparation of feedstuffs, e.g. methods of upgrading roughages, manufacture of feed blocks (FB), may require separate research. Conroy (2005) summarises the steps necessary for effective participatory research.

On-farm trials range from researcher led/researcher managed to farmer led/farmer managed. Farmers and extension workers must be involved at all stages of this process. Farmers have given a clear indication that the option tested would be adopted if proven suitable. To ensure relevance, rapid rural or participatory rural appraisal (RRA, PRA) should be undertaken with selected groups of farmers. On-farm trials should, where possible, include farmer practice as a control treatment. There is a scarcity of data on the quantitative needs of animals on low planes of nutrition, and feeding for maximum production may not be the right approach; the system of production, allowing for household resources, marketing opportunities, etc., has to be taken into account (Buttery et al., 2005).

However, possibly the most important component of the diet is water (Buttery et al., 2005; Smith et al., 2005a). In dry conditions supplying water to grazing and stall-fed animals can be a time consuming chore, but without adequate provision of water dry matter intake and performance will be constrained. Improved livestock, with exotic blood, will usually have a higher demand for water than indigenous stock, especially at high ambient temperatures. Young and lactating stock also have high demands.

Why involve the farmer in the research process (see Chambers et al., 1989)? There is little point in using limited resources for testing and promoting a technique that farmers cannot adopt, for example where an input may be too expensive or unavailable, where labour is not available, e.g. for forage conservation, or where cultural reasons prohibit adoption (urine, instead of urea, is an excellent material for upgrading poor quality roughages but its use is unacceptable in many communities).

3.1. Enhancing the nutritive value of cereal crop residues

The residues of cereal crops consist of the stem and some leaf material. They are fibre-rich and low in crude protein, both of which restrict dry matter intake. However, for many livestock farmers they are a major component of dry season feeding. Because of their fibrousness residues have to be broken down in the rumen, a process dependent on adequate numbers of cellulolytic bacteria being available. The rate of breakdown and passage through the rumen are major factors in determining intake. Improvement in nutritive value of a forage often depend on increasing the supply of rumen N, thereby increasing digestibility of the fibre. The background to efficient use of crop residues was extensively reviewed by many authors (e.g. Sundstøl and Owen, 1984).

Although this discussion will centre on treatment and supplementation of residues, the conservation of the nutrients they contain should start at the point of harvest. Prompt harvesting, as soon as the crop is dry enough to store following grain harvest, reduces the amount of leaf loss between the field and the store (the higher the leaf: stem ratio, the higher the nutritive value) (Manyuchi et al., 1990). Dry storage is necessary to prevent moulding (mouldy material is usually rejected by the animal, but if eaten can result in ulceration of the rumen wall, leading to death in extreme cases). The forage store, constructed of locally available materials, should consist of a raised floor, to stop rising damp and allow vermin control, in a roofed structure, to prevent rain damage, but with adequate ventilation (Wood et al., 2001). If the residues are to be used at a distance from the point of collection, e.g. because cropping is on lowland and livestock are kept in the hills, as in parts of Tanzania, or they are to be sold, then compaction of the forage through manual box baling should be considered (Massawe et al., 2003), thereby increasing the weight of material that can be transported in a single trip (volume not weight is usually the constraining factor when moving forages).

3.1.1. Supplementation

Supplementary protein increases intake and digestibility in ruminants receiving diets based on low quality forages, including crop residues. Digestion of these materials is dependent on an adequate population of cellulolytic bacteria, which needs a constant supply of degradable protein. Although ruminants are the only group of domestic livestock that can tolerate dietary non-protein nitrogen (NPN), usually in the form of urea, trials in which NPN has been compared with true protein sources have shown that responses to the latter are usually greater. Urea and its derivatives are quickly solubilised and generate a rapid response in the level of rumen ammonia, which the slowly fermentable energy source cannot use efficiently, to generate rumen microbial protein, before the ammonia is absorbed. Proteins with a slower solubility provide a steady supply of ammonia over a longer period, resulting in more efficient digestion of the forage and an increased rate of passage of digested material into the lower digestive tract. True proteins are also necessary for those animals unable to meet their protein requirement from rumen microbial protein synthesis by providing by-pass protein (that portion escaping degradation in the rumen) for utilisation in the small intestine. Lactating and rapidly growing young animals are likely to fall into this latter category, depending on the quality of the basal diet. The need to match the energy component of the diet with the available supplementary nitrogen source was emphasised by Preston and Leng (1987).

All forages contain some protein, varying in amount between species, stage of growth and season. Legumes are useful protein sources and, because of their ability to fix nitrogen in the soil, have the added advantage of improving soil fertility. Most grasses are rich in protein in the growing stages, but as the plant bulks and matures fibre levels increase and protein falls, thus decreasing digestibility and intake. This is particularly marked where there is a pronounced dry season (Elliott and Folkersten, 1961). It is also important to remember that forages are not only suppliers of protein but also the major source of energy, thereby raising the question of quality (high protein) or quantity (bulk energy). Although the provision of bulk is normally the target there is no one correct answer, but where conservation is practised time of harvest will be critical (see below); forward planning is essential.

Assuming that the bulk diet is low in protein use and choice of supplement is necessary. The first step is to ascertain what is available within the homestead (e.g. legume residues: soya; acacia tree fruits; cowpeas) or locally as by-products of a village industry (e.g. sunflower residue from ram-press oil production; olive cake). Purchased proteins include oilseed cakes, cereal grains and by-products of the milling industry. For most smallholders the deciding factors to this will be availability and cost (the ability to pay will depend on access to cash or credit and the likely return per unit of supplement).

The nutritive value of local protein sources may not be available in the mainstream literature because for example they are products of trees (IAEA, 2006) that grow in a specific environment or they are by-products of a local agro-industrial process. If naturally occurring products are eaten during grazing or browsing, with no deleterious effects and if the product can be collected and stored easily it should be considered as a potential supplement for feeding in times of scarcity, and should be drawn to the attention of the national agricultural research service (NARS) for evaluation. Table 1 lists representative protein feeds from the categories listed above and Tables 2 and 3 give examples of responses in goats and sheep to supplementation of residues.

3.1.2. Particle size and other physical treatments

Both cereal residues and coarse fodders consist mainly of stem. As collected they are not suitable for stall-feeding, although where stock are penned at night they are often put on the floors of kraals to be picked over. Their outer coat is lignified to give rigidity to the plant as it grows, and as a protection against the weather. To increase the rate of breakdown and fermentation in the rumen, thereby increasing rate of passage and ultimately dry matter intake, it is beneficial to reduce particle size (Walker, 1984) to increase the surface area of digestible material exposed to the rumen microbes. This can be achieved by:

Chopping, either by hand with a machete (panga) or chaff cutter (a simple machine based on a wheel, in which the spokes are cutters, and a handle to turn the wheel; some can be power-driven). Chopping is unlikely to increase intake and digestibility but will reduce selection.

Grinding requires a power-driven chopper/grinder, the degree of fineness obtained depending on the size of screen used. In practice removing the screen of a hammer mill gives a fine product and maximizes throughput from the mill. Dustiness can be a problem in stall-feeding, although sprinkling with water at the point of feeding will reduce this.

While chopping by hand involves less investment in machinery and power, it is labour intensive; Power-driven choppers are priced according to the degree of sophistication and range from mechanised chaff cutters to hammer mills, the cost of power depending on the fine-

Table 1
Protein and crude fibre content (g/kg dry matter [DM]), and DM digestibility, of some typical feeds available for dry season feeding (from Jayasuriya, 2002; Smith et al., 2005a)

Type	Protein content[a]	Crude fibre[a]	Digestibility[a]
Maize stover (straw)	Low	High	Low
Rice straw	Low	High	Low
Sugarcane tops	Low	High	Moderate
Bagasse	Low	High	Low
Dry season grazing	Low	High	Low
Legume tree leaves	Moderate to high	Moderate to high	High
Haulms and tops	Moderate to high	High	Moderate to high
Cassava leaf meal	High	High	
Brewers grains	High	High	Moderate to high
Tree fruits (e.g. Acacia spp.)	Moderate	Moderate to high	Low to moderate
Molasses	Low	Low	
Citrus pulp	Low	High	Moderate
Oilseed cakes	High	Low to high	High
Cereal bran	Moderate to high	Moderate to high	High
Cage layer manure	High	High	
Cereal grains	Moderate	Moderate	High

[a] Protein content (g/kg DM): low = <60, moderate = 60–110, high >110; crude fibre (g/kg DM): low = <60, moderate = 60–120, high = >120; digestibility (g/kg DM): low = <400, moderate = 400–600, high = >600.

ness of chop required. For feeding forage, either alone or in a loose mixed diet, particles of 1.5 cm will probably be used as efficiently as finely ground material and avoid the problems associated with dusty feeds. For inclusion in complete diets or concentrate feeds (both as a filler and to maintain a basic level of fibre in the diet) the smaller particle sizes may be required.

Soaking in water gives inconsistent benefits in terms of improved digestibility, but with ground materials it reduces dustiness and it provides an easy and safe way to feed urea with minimal risks of poisoning.

Stripping, done to remove the palatable leaves and top portion of the stem for use as feed, leaving the discarded stems to be used for fuel or left in the field as a source of organic matter (Massawe and Mruttu, 2005). Simple tools have been developed for stripping maize plants.

Excess feeding, that is feeding more than the animal will eat, allows selection of the most nutritious feed on offer, thereby increasing intake and digestibility. This has been demonstrated with sheep and cattle in two studies, with sorghum stover (Osafo et al., 1997) and maize stover (Smith et al., 1989).

3.1.3. Chemical and other treatments

The objectives of chemical treatment are (1) to break down the ligno-cellulose bonds to permit the entry of rumen bacteria through the outer sheaf of the stem; (2) to add nitrogen to the residue. Early work showed that a solution of sodium hydroxide increased digestibility of residues, but NaOH is a dangerous chemical, in that contact with human skin causes burning, and it does not contain nitrogen (Homb, 1984). However, processes have been developed to treat whole-crop cereals. Since then treatments with ammonia, either anhydrous or as a liquid, urea, local salts and urine have been developed. While NaOH is the strongest alkali of those tested, the latter group is easier to use and all contain nitrogen.

Table 2
Nutritive value of barley straw treated or not with ammonia or urea and covered with plastic sheeting or mud (from Ben Salem et al., 1996)

	US[a]	ATS[a]	UTSp[a]	UTSm[a]	S.E.M.
DM (g/kg)	874	870	752	846	
Crude protein (g/kg DM)	31	78	76	78	
Straw intake (g/kg $W^{0.75}$)	47.8[c]	61.1[a]	54.3[b]	55.3[b]	0.76
Organic matter digestibility (%)	58.8[b]	63.6[a]	61.9[ab]	60.1[ab]	0.40
Crude protein digestibility (%)	32.7[b]	51.9[a]	52.1[a]	54.2[a]	0.79
Daily gain (g)	56.6[b]	95.6[a]	92.1[a]	92.6[a]	1.16

Means in the row with different superscripts (a, b, and c) are different ($P < 0.05$). S.E.M., standard error of the mean.
[a] US, untreated straw; ATS, ammonia-treated straw; UTSp, urea-treated straw covered with plastic sheet; UTSm, urea-treated straw covered with mud.

Table 3
Examples of diets containing alternative feed resources and their effect on sheep and goats growth or milk yield

Basal diet (g DM/day)	Supplements (g DM/day)	Animal	Daily gain (g/day)	Reference
Barley straw	Concentrate (500 g)	Lamb	63	Ben Salem and Znaidi (2007)
Barley straw	Concentrate (125 g) OC-feed block (392)[a]	Lamb	66	Ben Salem and Znaidi (2007)
Oaten hay (770 g)	Concentrate (300 g)	Lamb	75	Ben Salem (unpublished data)
Oaten hay (903 g)	CP-feed blocks (425 g)[b]	Lamb	90	Ben Salem (unpublished data)
Wheat stubble grazing	None	Ewes	30	Shideed and Salman (1996)
	Feed block	Ewes	51	Shideed and Salman (1996)
	Sunflower seed meal	Ewes	44	Shideed and Salman (1996)
	None	Ewes	402[c]	Shideed and Salman (1996)
	Feed block	Ewes	888[c]	Shideed and Salman (1996)
	Sunflower seed meal	Ewes	867[c]	Shideed and Salman (1996)
Barley straw (514 g)	Barley (180 g) + soybean meal (155 g)	Lamb	108	Ben Salem et al. (2004)
Barley straw (321 g)	Cactus (618 g) + atriplex (433 g)	Lamb	81	Ben Salem et al. (2004)
Native pasture	None	Lamb	77	Le Houérou (1992)
	Cactus (130 g) + atriplex (240 g)	Lamb	101	Le Houérou (1992)
Atriplex nummularia browsing	None	Lamb	−35	Ben Salem et al. (2005a)
	Cactus (347 g)	Lamb	21	Ben Salem et al. (2005a)
Native bushland	None	Kids	25	Ben Salem et al. (2000a)
	OC-feed block	Kids	45	Ben Salem et al. (2000a)
	Cactus (100 g) + atriplex (100 g)	Kids	60	Ben Salem et al. (2000a)

[a] Olive cake-based feed block.
[b] Citrus pulp-based feed block.
[c] Milk yield (g/(ewe day)).

Ammonia has been used in Europe, North Africa mainly Tunisia, and North America, but is of greatest value as a contractor technique for large batches of fodder. In this case the farmer cannot treat his straw/stover due the high risk in handling this gas and the technical knowledge required. In practice, this technique is not adopted by smallholder farmers in dry areas.

Urea is the most commonly available, easily transportable in relatively small quantities and safe to use. However, urea does require safe storage as it is toxic to ruminants in large quantities and all monogastrics including humans (children should have no access to it). For the smallholder both cost and availability are possible constraints, with farmers having to prioritise between using urea as fertiliser, as a feed supplement or for forage treatment. The application process is to mix the urea in solution with water and to apply it to the forage at the rate of 5% of urea to the forage dry matter (DM) (5 kg urea/100 kg forage DM). The total amount of solution applied should be in excess of 20% of the weight of the fodder. The treated material should then be sealed to ensure that as the urea is converted to ammonia gas cannot escape. Storage in plastic bags, heaps covered with a plastic sheet or in pits (which can be sealed with plastic, weighted with soil), and then left for 3 weeks (Smith, 2002) have all proved satisfactory. The use of mud, used for rural house construction since many centuries, is also being used to cover stacks of hay and straw to protect them against rainfall. Based on this local knowledge, mud has been tested by Ben Salem et al. (1996) as a possible alternative to replace plastic sheets to cover urea-treated straw. Wheat straw treated with anhydrous ammonia or urea and covered with plastic sheets was similar in nutritive value to that treated with urea and covered with mud (Table 2). This cost-effective technique is especially applicable to smallholder farmers' conditions, where the forage is usually stored loose (unbaled) form. Irrespective of the cover used, on opening the treated forage should be left to aerate for a few hours before being fed, as the smell of excess ammonia may reduce intake.

Local salts include calcium hydroxide, calcium oxide, potassium hydroxide, sodium carbonate and materials such as magadi, available in Kenya. While not as effective as some materials they have the advantage of being cheap (Owen and Jayasuriya, 1989b).

Ash is produced in large amounts by rural populations who use wood and sometimes air-dried faeces as fuel for cooking. Wood and dung ash solutions (pH > 10) proved efficient in improving the nutritive value of cereal straws (Nolte et al., 1987) and sorghum stover (Ramirez et al., 1991). Wood ash treatment could be a cost-effective way to make better use of ligno-cellulosic feedstuffs, but efforts are still needed to transfer this technique to farmers.

Urine is probably the most freely available alkali containing nitrogen (Sundstøl and Owen, 1993). However, its use may not be acceptable in all communities. Collection from animals is not easy.

While these treatments have been shown to work, both in the laboratory and the field, their uptake is disappointing, although interest revives in difficult seasons. The reasons for this reluctance are not clear but are probably a combination of labour and cash constraints (Owen and Jayasuriya, 1989a). It should also be noted that future developments in the treatment of roughages is likely to involve bio-degradable materials such as enzymes (Colombatto et al., 2003).

3.2. Promising techniques for better use of agro-industrial by-products (AGIBPs)

Food processing generates large amounts of by-products, but only few of them (e.g. oilseed cakes, brewers' waste) are successfully integrated in livestock feeding. This is because most of these agro-industrial by-products are low in, and/or not balanced for the major nutrients. Additionally, the problem of handling and the difficulty of their use as fresh material for extended periods could be another reason for the limited use of by-products. For example, olive cakes, tomato pulp, citrus pulp and grape pomace are high in moisture (500–850 g/kg), thus mould would appear a few weeks after their production if storage is not adequate. Target mixing of some of these AGIBPs could be a solution to obtain a balanced feed for energy and protein. Attempts have been made through chemical treatments to improve the nutritive value of for example olive cake (urea and sodium hydroxide treatments; Sansoucy et al., 1985; Nefzaoui, 1999) and grape pomace (polyethylene glycol to deactivate tannins; Alipour and Rouzbehan, 2007). Although these treatments proved efficient in improving the nutritive value of some AGIBPs, their adoption by farmers is still limited due to the high cost, availability and/or the risky handling of these chemicals. Moreover, several farmers experienced some intoxication problems among their animals fed on the urea-treated material. Newly developed technologies can offer cost-effective solutions for integration of AGIBPs into ruminant feed calendars. Below, we will comment on feed block manufacture, pelleting and ensiling techniques.

3.2.1. Feed blocks

Feed blocks, also called multi-nutritional blocks, were being used in about 60 countries by the 1990s (Sansoucy, 1995). Many reasons may account for the wide adoption of this technology (see reviews by Sansoucy, 1995; Ben Salem and Nefzaoui, 2003). It must be stressed that FB should be considered supplements for ruminants on low quality roughages (cereal straws, gramineous hays, etc.), pastures or rangelands. These supplements are expected to enhance digestion of these fibrous feedstuffs, thus to improve livestock performance.

3.2.2. Achieving a balanced formulation of nutrients

The benefits from FB depend on an appropriate formulation. Examples of formula reported in the literature are given in the review by Ben Salem and Nefzaoui (2003). The feed block is a solidified mixture of AGIBPs, binder (e.g. quicklime, cement, and clay), urea, salt and minerals. Ingredients should be chosen on the basis of their local availability, cost and nutritive value. For example molasses or processed prickly pear fruits could be mixed with olive cake and rapeseed meal as sources of energy, fibre and proteins, respectively. Solidification of the ingredients with a binder will ensure the animal consumes small amounts of the FB over the day. This intake regulation will result in a controlled supply of nutrients, energy, nitrogen and minerals, to the animal, necessary to stimulate optimum rumen fermentation, thereby improving digestion of low quality diets (Leng, 1990).

With high quality roughages, like alfalfa hay and fresh grass fed in a cut-and-carry system, or grazed directly by animals, there would be no nutritional advantage in offering FB as a source of energy or protein.

Other advantages of feed blocks include their possible use as carriers of anthelmintics, for grazing animals (Anindo et al., 1998), specific minerals and vitamins, to increase reproductive performance in sheep (Al-Haboby et al., 1999), or to provide polyethylene glycol, a tannin-deactivating reagent, to stall-fed (Ben Salem et al., 2000b, 2003) or free-grazing sheep on *Acacia cyanophylla* Lindl. (syn. *Acacia saligna*).

3.2.3. Reducing feed cost

Recommending an alternative feed supplement more expensive than that used in normal practice (e.g. barley) will be not readily accepted by farmers, especially resource-poor smallholders. Cereal grains (barley, maize, etc.) are needed for human consumption, as well as in intensive pig, poultry and ruminant production. The situation is acute in dry countries where these feed resources are partially or totally imported. In any case farmers try to prioritise the distribution of grain starting from the needs of the family and then of large animals, especially dairy cattle. Sheep and sometimes goats may have access to small amounts of these feed supplements for fattening. However, many farmers cannot afford to purchase grain for stockfeed so substitutes such as blocks, which can partially or totally replace traditional concentrate feeds in the diet of sheep, are sought. Animal response to this substitution will depend on the formula of the feed blocks. Examples of responses of sheep and goats to feed blocks are reported in Table 3. Ben Salem and Znaidi (2007) have shown that olive cake-based feed blocks can replace up to three quarters of the amount of concentrate (mixture of barley and wheat bran) without decreasing lamb growth with a reduction in feed cost of about 20%. In another trial, Ben Salem (unpublished) obtained higher daily gains in lambs fed on oaten hay supplemented with olive cake, apple pomace, or citrus pulp-based feed blocks in place of concentrate. Feeding of lambs could be reduced by up to 40% through the use of feed blocks in place of some concentrate feeds.

3.2.4. *Easy to make, store, transport and use*

An easy technique has been developed to make feed blocks. Locally available and simple tools were used by farmers to hand-make small amounts of blocks (Ben Salem et al., 2005c). Mechanised mixing and moulding is recommended when large amounts of FB are required. This reduces the costs of manufacture and is often undertaken by farmers associations. Adequate solidification and the addition of salt are especially necessary if the blocks are to be stored for a long period. Storage allows flexibility in resource management as the blocks can be made when the raw materials are available to be carried over into periods of feed scarcity. In many systems it is usual for supplements to be fed in the barn before or after grazing. This is time consuming operation which results in an asynchronous supply of nutrients to the rumen. This situation can be overcome by the distribution of feed block in the pasture.

3.2.5. *Agro-industrial by-products pellets*

Making pellets of a prescribed mixture of AGIBPs to optimise their feed value could produce supplements to replace high quality pellets such as those based on lucerne, which few smallholders can afford. The formulas used for FB manufacture could be adapted for this but urea should be replaced by an oilseed cake or legume, to avoid the risk of intoxication if large quantities of the pellets are consumed. A binder would not be necessary as pressure in the pelleting machine will ensure stability of the pellet. Although this technique seems interesting, we are unaware of any published paper on such a technique. However, Nefzaoui and Ben Salem (unpublished data) developed a formula and evaluated the nutritive value of olive cake-based pellets (OC pellets). The formula included solvent extracted olive cake (350 g/kg), wheat bran (350 g/kg), wheat flour residue (110 g/kg), rapeseed meal (150 g/kg), salt (20 g/kg) and mineral and vitamin supplement (20 g/kg). An *in vivo* trial on adult Barbarine sheep showed that the OC pellets were relatively high in crude protein (165 g/kg DM) and apparent digestibilities of dry matter, crude protein and cell wall (NDF) were satisfactory (>60%). The cost of making 1 kg of OC pellets was about 50% lower than the market price of alfalfa pellets. Numerous Tunisian farmers have tested the OC pellets on their sheep and goat flocks and were satisfied with this novel feed. In contrast to feed blocks, AGIBPs pellets can replace all or some of the basal diet provided that they include a fibrous source like olive cake to encourage normal rumination. Quality pellets will depend on the ingredients, especially the sources of energy and protein. Promotion of this technology to farmer associations and light industry should be encouraged especially in dry areas.

3.2.6. *Ensiling of agro-industrial by-products*

High moisture, by-products exposed to the sun for drying either ferment, or go sour or mouldy very quickly. They also lose considerable quantities of soluble nutrients in the effluent, and may become a breeding ground for flies. Additionally, the transportation costs of these AGIBPs are high. Several studies (e.g. Hadjipanayiotou, 1999, 2000; Scerra et al., 2001; Bampidis and Robinson, 2006; Denek and Can, 2006) have shown that high moisture AGIBPs (e.g. olive cake, citrus pulp, and tomato pomace) can be successfully ensiled with crop residues (e.g. chopped straw, partially dried grass or legumes), which are low in moisture. Silages containing AGIBPs can replace conventional feedstuffs, including concentrates. Scerra et al. (2001) showed that citrus pulp silage (mixture of orange pulp and chopped wheat straw) can replace all the oat hay and some of the concentrate without affecting lamb growth rates and carcass and meat quality. The feeding cost was lower in the silage diet than the control diet (approximately 80% oat hay and 20% concentrate). However, a major constraint to ensiling large quantities of material can be the cost of machinery and construction of large silos. In a number of studies on the potential for ensiling AGIBPs, Hadjipanayiotou (2000) obtained interesting results with olive cake-based silage. This by-product is available in appreciable quantities in most Mediterranean countries but it is not widely used in livestock feeding because some farmers consider it toxic for ruminants because its use can decrease lamb growth and ewe milk yield. The seemingly poor response to olive cake is because farmers compare the response to that of their traditional supplements (e.g. barley, wheat bran, and alfalfa pellets) for which it is substituted when the price of these feeds is too high. It is well established that olive cakes (crude or solvent extracted) have a low nutritive value due to the high lignin content and the high proportion of nitrogen bound to ligno-cellulose (Nefzaoui, 1999). Moreover, olive cakes are seasonally available and quickly become rancid and mouldy due to their high oil (crude olive cake) and moisture content. However, olive cake is considered an emergent dry season feed. For example in the desert of Tunisia, olive cake is purchased by smallholders for their flocks of sheep, goat and dromedaries. To better utilise olive cakes, they should be mixed with other AGIBPs in the form of feed blocks or silage. Hadjipanayiotou (1999) described an ensiling technique for storing and feeding crude olive cake that is simple, safe and low-cost for the farmer. In a review paper, Hadjipanayiotou (2000) summarised the potential use of olive cake silage in sheep, goat and cattle feeding. He showed that replacing 30% of a common diet (concentrate mixture: 160 g crude protein/kg DM; concentrate: hay 65:35) with crude olive cake-based silage (mixture of olive cake, maize grain and poultry litter, 7:1:2) offered to Chio ewe lambs increased growth rate compared to a standard diet (53 g/day vs. −27 g/day). Goat kids on the standard or silage diets grew similarly. In another trial, this author concluded that partial replacement of barley hay with plain crude olive cake had no effect on total and fat corrected milk yield of ewes and goats. Based on these findings it was clear that ensiled olive cake could partially replace conventional roughages in diets of growing and lactating ruminants. Therefore, AGIBPs ensiling can be a cost-effective technique which fits well with smallholders' conditions and objectives. For better adoption of this approach ensiling these feed resources in small plastic bags should be considered.

3.3. Fodder trees and shrubs

Much of the semi-arid and arid tropics and sub-tropics are covered with indigenous trees, shrubs and woody plants, many of which (e.g. *A. cyanophylla* Lindl., *Acacia tortilis*, *Dichrostachys cinerea*) produce edible leaves and fruits. Exotic species of trees are usually faster growing and many are leguminous, making them suitable for inclusion into cropping areas, for live fences, alley cropping and intercropping. The fixation of nitrogen, contribution to mulch and reduction of erosion is in addition to providing forage (Topps, 1992). A comprehensive review of the trees of Southern Africa, together with their uses, is given by Coates-Palgrave (1983) and for the acacia species common in Zimbabwe by Timberlake et al. (1999). In Zimbabwe, the importance of browse in the diet of free ranging goats was assessed by Sibanda (1986), who reported that goats on acacia thornveld spent up to 60% of their feeding time browsing. In another trial *Acacia boliviana* and *Leucaena leucocephala* were both ensiled in a 1:1 mix with forage maize to feed to dairy cows. Estimated dry matter digestibility of the acacia/maize mix was similar to maize alone (62.2 vs. 63.8), both higher than the Leucaena/maize mix (57.6) (Mugweni et al., 2001).

Several forage species, including the acacias, contain tannins, which can have both beneficial and harmful effects on livestock (e.g. see Anim. Feed Sci. and IAEA TECDOC, 2005). The use of tree fruits as dry season protein supplements has been evaluated by (Tanner et al., 1990; Ncube and Mpofu, 1994; Smith et al., 2005b). Most of the protein of tree fruits is contained in the seeds, but although Tanner et al. (1990) found that 94% of the seeds of *A. nilotica*, one of the most widespread of the Acacias in Africa, were digested by sheep, Smith et al. (2005b) reported very low intakes in goats of whole fruits of this species when fed as a dry season supplement. Of the fruits evaluated by Smith et al. (2005b), *D. cinerea* was the most readily eaten by female goats and resulted in the largest reductions in kid mortality, especially in twin-born kids (in Southern Africa kid mortality can be as high as 50%). While it is possible to rank tree fruits according to their nutritive value, a participatory rural appraisal (Kindness et al., 1999) carried out in Zimbabwe found that the preferred fruit species in all four districts surveyed depended on availability. They also found evidence of fruits being marketed. In Kenya, fruits are being collected on contract by resource-poor non-livestock owners for goat keepers to feed stall-fed goats (Ahuya, pers. comm.). *Prosopis juliflora* fruits have replaced a supplement of barley grain in the diets of breeding goats in India (Conroy, 2005), increasing both the number of does kidding and the number of twins born. The data do not extend to giving the number or weight of kids weaned, which are possibly the most critical information for the goat producer. In Karnataka

State, India, Conroy (2005) reported that seed digestibility was around 95%, a similar value to that quoted above (Tanner et al., 1990). However, Smith et al. (2006) were concerned that the protein/tannin complex in many tree fruits was an anti-nutritional factor that merited closer study. *In vitro* trials with NaOH were effective in breaking the bonds, but as with crop residue improvement, NaOH is not suitable for on-farm use. Further trials using wood ash, available in virtually all homesteads, in solution and soaking whole fruits for 40 h before feeding, has increased kid survival and live-weight gain. Wood ash treatment was also efficient in deactivating tannins in *A. cyanophylla* Lindl. foliage, thus improving the nitrogen value of the diet (Ben Salem et al., 2005b). However, like other alkalis, wood ash treatment appears to reduce water-soluble carbohydrates. Therefore when possible, energy supplementation should be recommended whenever ruminants receive wood ash treated foliage or fruits of fodder shrubs and trees. This topic merits further research.

Mixing of shrubs/trees is *a priori* an easy and efficient way of overcoming a nutrient deficiency and/or imbalance of a single woody species and also can dilute the negative effects of undesirable secondary compounds, like tannins and oxalates, contained in some of these species. For example, lambs lost weight when fed *A. cyanophylla*, *Atriplex nummularia* foliage or *Opuntia ficus indica* f. *inermis* (spineless cactus) cladodes alone or with low quality feedstuffs (e.g. cereal straws). However, when fed together, performance improved. This feeding method will save money for the farmer. The complementary role of cactus and atriplex as alternative feed resources for sheep and goats was reviewed by Ben Salem et al. (2002b). In brief, both of these shrub species are drought tolerant and are evergreens. The high salinity of atriplex foliage is diluted by the abundant water in cactus cladodes. Cactus, thanks to its high soluble carbohydrate content, may overcome the energy deficiency in atriplex foliage. However, atriplex contributes both nitrogen and fibre, which are extremely low in cactus cladodes. Table 3 gives illustrations on the growth performances of stall-fed or grazing sheep and goats receiving some shrub-containing diets. The benefit of these diets should not be viewed in light of production performances alone (i.e. daily gain, milk yield, etc.) but also on the basis of availability of feed resources and of the balance between the farmer's input and income. For example, the farmer can accept a daily gain of 80 g when lambs on straw are supplemented with cactus and atriplex rather than with barley and soyabean, although the latter expensive supplements results in a higher growth rate (ca. 110 g/day). Moreover, many trees and shrubs also produce fruits for human consumption (e.g. cactus fruits), and have a role in erosion control, wood production, etc.

3.3.1. Benefits from tanniniferous fodder shrubs and trees

3.3.1.1. In situ protein tannin. Until recently tannins were considered as anti-nutritional compounds, which decrease the nutritive value of numerous feedstuffs thus reducing productive and reproductive performances of ruminants (Makkar, 2003). However, the advantageous use of these compounds in sheep feeding has been demonstrated in a set of *in vivo* studies carried out in New Zealand. The association of *Lotus pedunculatus*, *Lotus corniculatus*, or *Hedysarum coronarium* (Sulla), all tanniniferous herbaceous legumes, with berseem or alfalfa resulted in increased growth performances and milk yield together with improvement in some reproductive parameters. It is probable that lotus tannins increased the proportion of protein escaping rumen degradation and consequently increased the flow of amino-acids in the intestine. The positive effects of tannins present in temperate forages on sheep performance were reviewed by Min et al. (2003) and Waghorn (2007). However, these plant species, like most common herbaceous legumes, cannot withstand the conditions common to very dry areas, unlike numerous tannin-rich woody species. Although the negative effect of the foliage and fruits of tanniniferous species on livestock performance has been demonstrated, the administration of small amounts of such vegetation, either fresh or sun-dried, in concentrate diets can increase sheep growth. Ben Salem et al. (2005d) demonstrated benefits from adding small amounts of *A. cyanophylla* foliage (acacia) to soyabean meal (SBM) in the diets offered to Barbarine lambs. Lambs receiving oaten hay ad libitum supplemented with 200 g soyabean meal and 100 g acacia grew at a rate of 67 g/day compared to those receiving the above diet, but without acacia (42 g/day). This increase was dependent on the acacia and SBM being offered sequentially to synchronise the availability of acacia tannins and SBM proteins in the rumen. Nsahlai et al. (1999) concluded that feeding sheep oilseed cake after they had eaten *Acacia albida* pods (rich in tannins) enhanced live-weight gain. Further investigations to evaluate tannin activity of woody species growing under dry conditions are needed.

3.3.1.2. Anthelmintic activity of tanniniferous plants. Globally parasites are one of the major factors hindering the productivity of livestock, especially those dependent on grazing. A wide range of anthelmintics have been used to reduce faecal egg excretion. However, resistance has been noted to many of the proprietary anthelmintics currently on the market due to overuse. They are also very expensive, often beyond the reach of smallholder livestock keepers. Effective, cheap and available alternatives are needed to solve this problem. Recent studies confirmed that tannins in some plant species reduced egg excretion, worm burden and parasite development in sheep and goats (Hoste, 2005), confirmed in goats eating *Sericea lespedeza* (Min et al., 2003) and sainfoin hay (Paolini et al., 2003). The anthelmintic activity of some other legume forages (*L. pedunculatus*, *L. corniculatus*, *H. coronarium*, and *Onobrychis viciifoliae*) have also been demonstrated in sheep and goats (e.g. Athanasiadou et al., 2001; Molan et al., 2000a,b, 2002; Niezen et al., 2002). Some acacia species like *A. karoo* (Kahya et al., 2003) and *A. cyanophylla* (Akkari et al., 2008) considerably reduced faecal egg output by goats and sheep. In brief, some plants containing tannins have proved effective against infection by gastrointestinal nematode parasites. To reinforce the advantageous use of tanniniferous plants in sheep and goat feeding, it is necessary to determine the appropriate levels of tannins in the diet that reduce faecal egg excretion and at the same time increase the amounts of dietary proteins escaping the rumen.

Although a wide range of suitable fodder shrub species have been identified by scientists as beneficial in rangelands, farmers are still reluctant to adopt them. For example irrigation is needed during the first two to three years of *A. cyanophylla* Lindl., *A. nummularia*, and *Medicago arborea* establishment, often not available on-farm. Additionally, these shrubs need pruning at 2–3 years intervals to ensure plant rejuvenation for which labour may not be available.

3.3.2. Cactus, a miracle plant?

A potential solution to forage production from arid and semi-arid rangelands is the development of production systems based on indigenous species with relatively low water requirements. Multi-purpose shrubs adapted to harsh environments with minimum inputs needed for their establishment and use are, in general, welcomed by farmers. Young cladodes derived from several *Opuntia* species are used in some Latin American countries as vegetables. Cladodes have numerous medicinal applications (e.g. regulation of weight and blood sugar, or to maintain fibre intake). Cochineal is produced by drying and milling adult female *Dactylopius coccus* Costa, parasitic insects that host on cactus pear cladodes. Cactus is also used industrially, for fuel production, as a protecting agent against corrosion, as a building material to improve stability and compressibility and clarification of waste water (cactus hydrocolloids) (Stintzing and Carle, 2005).

Described variously as “miracle plant”, “dromedary of the vegetation world”, and “the bank of life”, cactus can contribute in ameliorating the livelihoods of rural populations in dry areas. Farmers and herders in North Africa have long relied on it as a feed source for livestock, fencing material, and fruit for human consumption. Due to the Mashreq and Maghreb projects, cactus planting and subsequent use in animal feeding is expanding in West Asia (e.g. Jordan, Pakistan, and Syria). Thanks to other projects, this plant species is being established and its potential is under evaluation in other African countries such as Ethiopia. This plant exhibits crassulacean acid metabolism (CAM) and uses water very efficiently and, therefore, is able to withstand drought and extreme heat (Le Houérou, 1996). These CAM plants are commonly considered as drought resistant because they store considerable amounts of water in their shoots as well as fixing CO_2 at night; thereby reducing transpiration as the air temperature falls, resulting in less water loss at night than during the day. Cacti grow and survive in infertile and shallow soils, with highly efficient use of water, reflecting a unique root adaptation strategy. The success of *Opuntia* might be related to its distinctive reproductive biology. It grows rapidly and generates high biomass yields. Vegetative multiplication is more efficient than sexual reproduction (Reyes-Agüero et al., 2006).

Cactus is used in some countries (e.g. Brazil, Chile, Morocco, Mexico, South Africa, and Tunisia) as an emergency feed supplement for ruminants in periods of severe drought. Overall, cactus cladodes are high in water (850–900 g/kg), carbohydrates (640–710 g/kg DM) and calcium (40–80 g/kg DM), but low in fibre (NDF, 170–280 g/kg DM) and crude protein (25–60 g/kg DM) (Nefzaoui and Ben Salem, 2002; Stintzing and Carle, 2005). The high level of oxalates identified in cactus cladodes (70–150 g/kg DM) suggests that calcium would be unavailable for the rumen microflora and host animal (Ben Salem et al., 2002b) but ruminants can consume large amounts of cactus cladodes, and thus oxalates, without any serious effect on ruminal fermentation or intoxication being observed. The high sugar content of cladodes also had no detrimental effect on rumen fermentation. Mucilage appears to reduce salivation thus avoiding a rapid decrease of rumen pH. The association of a fibrous feedstuff (e.g. straw or hay) with cactus is recommended to promote normal rumination and to avoid digestive disturbances. Cactus was found a cost-effective supplement for sheep fed on low quality diets and, Ben Salem et al. (2004)

used it to replace barley as a supplement in the diet of Barbarine lambs. Meat quality has also been improved by inclusion of cactus in the diet, in that the linoleic acid content was higher than after feeding barley as a supplement (Abidi et al., unpublished). The association of cactus with a protein source (e.g. soya bean meal, *A. nummularia* foliage, etc.) is beneficial, with better responses in growth to those obtained with traditional supplements (barley and soya bean meal) (Ben Salem et al., 2004). In the absence of legume shrubs, the provision of protein feedstuffs by smallholders is not easy due to their high cost and availability. Increasing the protein content of cactus cladodes should be investigated. Some selected clones of cactus (i.e. clone TAMUK accession 1270) have been shown to have higher than normal (30–50 g/kg DM) crude protein (CP) contents of 110 g/kg DM. Under extreme cold (temperature of −15 to −20 °C), the hardy *Opuntia ellisiana* accessions 1360 and 1364 are the only spineless clones adaptable for forage production (Felker and Inglese, 2003). Increasing the nitrogen content of cactus cladodes should be fully investigated together with a breeding programme. Nitrogen fertiliser is another possibility to reach this latter objective.

Water scarcity and high temperatures are characteristics of dry areas. Water is required by the animals for at least two different purposes, as an essential nutrient and component of the body and to assist the animal to reduce “heat load” by conductive or evaporative cooling (More and Sahni, 1981). Since dry matter intake and water intake are inter-dependent, the low performances of small ruminants under dry conditions could be partly due to water availability and quality. In the absence of watering points, the animal will spend more in selecting and consuming plants rich in water. Except for cactus, we are not aware of any succulent plant that can withstand the conditions of dry and hot areas. Cactus cladodes are considered by farmers from these areas as a welcomed source of water for their animals, especially during hot periods. Indeed, the feeding of fresh cactus assists with the problems of watering livestock and Ben Salem et al. (1996) showed that adult sheep obtained their requirements when they consumed 300 g DM daily of cactus cladodes. Barbarine lambs receiving fresh cactus ad libitum and about 200 g of barley straw during the summer season drank insignificant amounts of water during the hottest months (June–August, 35–45 °C) in Tunisia (Ben Salem et al., 2002a).

Cereals dominate cropping in arid or semi-arid areas, although yields are frequently low because of the climate and poor agronomic practice. Other crops, including forage grasses and shrubs are often restricted although intercropping of cereals and shrubs has been adopted by some farmers. Established trees and shrubs, usually leguminous so that the soil benefits from both mulch and nitrogen fixation, are cut back when the cereal crop is planted and then periodically pruned during the growing season to prevent shading and reduce competition with the associated food crops. After harvest the woody species are allowed to grow freely to produce foliage to be fed to livestock (Smith, 1992). Among the advantages of this system are (i) soil enrichment; (ii) increased crop yields; (iii) a reduction in the number of weeds; and (iv) improved animal performance. Alley cropping systems have been successfully adopted in many countries. Properly managed, alley cropping allows diversification to benefit from several markets. It also promotes sustainability in both crop and livestock production. The benefits from cactus–barley cropping system have been evaluated in Tunisia (Alary et al., 2006). Compared to barley alone, the total biomass (straw plus grain) of barley cultivated between the rows of spineless cactus increased from 4.24 to 6.65 tonnes/ha and the grain from 0.82 to 2.32 tonnes/ha. These results are due to the change of the micro-environment created by alley cropping with cactus, which creates a beneficial “wind break” role, both reducing water loss and increasing soil moisture. The barley crop stimulated an increase in the number of cactus cladodes and fruits, while the cactus increased the amount of root material contributing to the soil organic matter.

In brief, there is an increasing interest in cactus cultivation. If we consider that a number of uses for cactus pear fruits are possible, we realize the importance of this crop to humans, both as food and in other applications, as livestock feed, where it both improves performance and is affordable, and for its positive impact on dry area ecosystems.

3.4. Forage conservation

Excess forage harvested in the growing season and stored for feeding in the winter or dry season is the basis for feeding in most ruminant production systems. The forage can either be stored dry, as hay, or as silage. The method of conservation will be influenced by climate, what the conserved forage is to be used for, the tools and machinery available and the feeding system (Payne, 1990).

Hay is harvested when the plant reaches the flowering stage and is dependent on good drying conditions, with low humidity and air movement being more beneficial than still sunny weather. The cut crop needs turning, to allow the air to penetrate the swath, or placing on racks or tripods. When dry (85–88% DM) it should be stored under cover, but air must be able to circulate in the stack to minimize the risk of mould formation (storage of hay in the wet tropics is unlikely to be successful) and spontaneous combustion. Forage stores described above are recommended. The amount of mechanisation will depend on the amount of hay to be made, with small quantities hand tools will suffice. Box baling (Massawe et al., 2003) can ease the work of moving hay. Legume hays, often only available in small quantities as a result of growing beans or oilseeds, are usually rich in protein and can be used as supplements with poor quality roughages (Smith et al., 1990).

Standing hay is forage that is left *in situ* for grazing. The disadvantages of this approach are that there is little control of the amount grazed both by domestic and wild animals, thereby increasing the risk of running out of forage before the next crop is available, fire and termite damage. As the dry season progresses, protein content of the crop decreases rapidly and fibre content increases, both due in part to senescence and loss of leaf material.

Silage is the storing, in anaerobic conditions, created by compaction of the material and exclusion of air, to allow the conversion of plant sugars to lactic acid, of green forage, as cut or after wilting, especially necessary for succulent crops (McDonald et al., 1991). Crops low in fermentable carbohydrates may need an additive, e.g. molasses, maize meal or a purchased product, to ensure this. The stage at which the crop is cut will depend on whether it is needed as high energy/high protein feed, when it will be cut at an early stage, or as a bulk feed, when nutritive value will be lower but the quantity harvested will be greater (Payne, 1990).

In intensive livestock production silage making requires expensive machinery and storage facilities. However, the scale of operation will depend on the number of animals to be fed, the length of the feeding period and the level of production. The crop to be ensiled, the methods of ensiling and storing and the overall cost must also be considered. With all silage making systems there will be some wastage, both during the making period and without adequate control during usage. When few animals are involved a small silage face exposed during usage will minimize wastage.

In semi-arid Zimbabwe reject 25 kg fertiliser bags have been used as ‘mini-silos’, compaction being achieved by sitting on the filled bag and then twisting the top down as tightly as possible. A range of materials have been ensiled, including Napier grass hybrids (6–10 tonnes DM/year) and forage sorghum (12–14 tonnes DM/year). Forage maize is being planted by some farmers in preference to grain maize, but usually when associated with dairying. Clay solids and strategic irrigation give higher yields of forage than sandy soils totally rain-fed (Titterton and Bareeba, 2000). Plastic bags need storing in a vermin proof store, ideally close to the point of feeding. Bags have been reusable over several years.

Table 4
An example of a feeding calendar for goats in a dry area of Zimbabwe (underlining of symbols indicates greatest reliance on a particular feed resource)

	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Collected tree fruits								$\underline{*}$	$\underline{*}$	*		
Collected crop residues								$\underline{*}$	$\underline{*}$	$\underline{*}$		
Fallen leaves and fruits					$\underline{*}$	$\underline{*}$	$\underline{*}$	*				
Crop residues in fields				*	$\underline{*}$	*						
Dry leaves and dry grass				$\underline{*}$	$\underline{*}$	*						
New shoots										*	$\underline{*}$	
Green leaves and grass	$\underline{*}$	$\underline{*}$	$\underline{*}$	$\underline{*}$	$\underline{*}$						$\underline{*}$	$\underline{*}$
Feed shortage						*	*	*	*	*	$\underline{*}$	

Source: From Kindness et al. (1999).

3.5. Feed calendars

Over 12 months most grazing systems consist of periods of growth and periods of scarcity. The wet, or growing season is often not seen as a problem, except where land pressure is intense and no grazing is available at this time, and the dry season as being a time of scarcity in which output will be reduced or stop (i.e. low growth rates or live-weight loss; cessation of lactation). There is a need to shift towards planning for an annual feeding cycle, which, as in intensive livestock production systems, is geared to year round production. Feed calendars can range from the very simple (e.g. Kindness et al., 1999; see Table 4) to those requiring a computer to compile. However, all feed calendars are designed to assist with allocation of feed produced during the growing season but used over the annual livestock production cycle. To achieve this, the amount of feed, the number of animals and the production requirements of those animals need to be known. The simplest calendars will take into account the estimated resources, and when they are available, together with the total number of animals to be fed, thus allowing likely periods of scarcity to be identified. More complicated versions will include livestock species (cattle, goats, sheep, equines, etc.), class of stock (male, female, young, growing, adult) and physiological state (fattening, lactating, pregnant, etc.).

3.6. Compensatory growth

Harsh environments impose stress on livestock growth. This usually results in slow growth in the dry season, often regarded as part of a normal growth cycle especially in smallholder owned livestock, or it can be so severe that permanent stunting results. Compensatory growth is the enhanced growth rate exhibited on realimentation after a period of underfeeding (O'Donovan, 1984). The response to compensatory growth depends upon the age of the animal at restriction, the type of restriction, the severity and duration of undernutrition, the duration of realimentation, the level of intake, length of the period and the nutrient content of the diet. Steers restricted in two dry seasons failed to compensate fully, resulting in depleted carcasses at slaughter (Smith and Manyuchi, 1992). Compared to other breeds, e.g. thin-tailed sheep, the Barbarine sheep (a Tunisian fat-tailed breed), and especially the ewe, is well adapted to harsh conditions mainly because of its ability to deposit and mobilise body reserves (Atti et al., 2004).

4. Economic impact of some technical options

Benefit–cost ratio is a good indicator of the performance of a technology and may affect its adoption by farmers. However, studies on economic impact assessment of technical options to alleviate drought impact on small ruminant performance are scarce. ICARDA, through the Mashreq and Maghreb project, assisted member countries in assessing the impact of improved technologies in crop (e.g. cactus and shrub plantations, alley cropping, improved barley varieties, forage legumes) and livestock production (e.g. feed blocks, improved rams, early weaning) systems in the West Asia and North Africa region. Difficulties could be encountered in pricing some options (e.g. forage legumes) for impact assessment, as the market for these options could be not developed yet in some countries. Moreover, the use of specific techniques in emergencies such as drought long-term survival/productivity may be the driving factor than short-term economics. Subsidization policy which differs among countries could interfere with the economic benefits of a technology. For example, while urea used for straw treatment or as ingredient in feed blocks is heavily subsidized in some countries, it is partially or not subsidized in some other countries. The price of this reagent varies significantly between urea producing and urea importing countries. In Tunisia, urea (imported reagent), plastic sheet and labour represent 66, 22 and 12% of the total cost of straw treatment with urea. Some extra-costs could be necessary to optimise the benefit from some specific technologies. Grinding is basically high energy consuming, expensive, but it is often used only for creating a fibre portion for concentrates. Chopping, although energy demanding, improves forage intake, also for stall-feeding is practical to cut waste.

Different approaches have been used in evaluating the economic benefits of some technologies transferred to communities in some dry areas. A first approach could be based on the opportunity cost concept by pricing, for example, the forage crop or the feed blocks, for example, at the price level of the alternative crop or common concentrate feed. Another approach could be based on the additional return obtained from sheep or goats as a result of the increase in body weight gain and milk production due to the use of alternative feed resources in livestock feeding. It is worth to note that some technologies like cactus and shrub plantation are not expected to have a wide market level impact, but farm level impact is more relevant in this case. Although the impact of these alternative feed resources on the use of common feedstuffs (hays, straws, barley, concentrate, etc.), thus on feeding cost could be estimated, it would be difficult to consider some indirect benefits, like the impact on environment factors (e.g. soil fixation and fertility) in the assessment of economic impact of shrub plantation. Overall, the impact of technologies transferred to target communities under the framework of the M&M project was calculated using the benefit to cost (B/C) ratio and/or the internal rate of returns (IRR). Case studies showing the economic benefits of some transferred technologies are reported in Table 5. In Iraq, high economic return is associated with the use of feed blocks in sheep feeding. The B/C ratio implies that an additional return of 0.56 Iraqi dinars (ID) is associated with each ID invested in feed blocks (Shideed, 2005). The high IRR with cactus plantation in Algeria (Redjal, 2005) and Tunisia (Elloumi et al., 2005) supports the profitability of this option even under low levels of fruit production or in marginal lands. The highest IRR was obtained with cactus–barley alley cropping and indicates clearly the efficiency of research investment in this technology. These results clearly demonstrate that cactus is a profitable crop for arid and semi-arid environments because of its low establishment and maintenance costs. It also allows farmers to crop cereals on marginal lands to control erosion, especially on sloppy lands. Atriplex plantation in the form of alley cropping with cereals is also profitable for Moroccan farmers (Laamari et al., 2005). Cropping improved varieties of barley in Jordan (Akroush and Awawdeh, 2005), Lebanon (Naddaf et al.,

Table 5
Economic benefit of some technical options transferred to farmers in the low-rainfall areas of West Asia and North Africa

Technologies	Countries	Benefit/cost	Internal net return (IRR, %)	Increase of net return (%)	Ref.
Feed blocks	Iraq		87		Shideed (2005)
	Tunisia	1.56	57–58		Elloumi et al. (2005)
	Jordan			18	Akroush and Awawdeh (2005)
Improved barley varieties	Jordan			15	Akroush and Awawdeh (2005)
	Lebanon			9–29	Naddaf et al. (2005)
	Morocco			43	Laamari et al. (2005)
Cactus plantation	Algeria		71–99		Redjal (2005)
	Morocco	2	11		Laamari et al. (2005)
	Tunisia		73–80[a]		Elloumi et al. (2005)
			61–66[b]		
			81–89[c]		
Atriplex plantation	Morocco		79[d]		Laamari et al. (2005)

[a] Cactus planted in natural rangelands.
[b] Cactus planted in marginal cereal lands.
[c] Cactus planted in the form of alley cropping with barley in marginal cereal lands.
[d] *A. nummularia* planted with barley (alley cropping).

2005) and Morocco (Laamari et al., 2005) increased the net return by 15, 9–29 and 43%, respectively.

To summarise, technology is the most important force in increasing agricultural productivity in the long term. However, the rate of adoption of a new technology is subject to its profitability, degree of risk associated with it, capital requirements, agricultural policies and socio-economic characteristics of farmers. The assessment of the economic benefit of a technology is necessary to evaluate its performance and its effect on farmers' income. Based on the data reported in Table 5 it is clear that cactus plantation in the form of alley cropping and feed blocks use are profitable technologies which could be recommended to smallholders in dry areas. It would be interesting to proceed with the assessment of the economic impact of the set of technologies reported in this paper and others (i.e. straw treatment, agro-industrial by-product ensiling, etc.).

5. Technology transfer and adoption

"Research in support of poverty reduction is based on the implicit assumption that livelihoods are constrained by production and/or efficiency, which are in turn constrained by (lack of) knowledge" (Garforth, 2004). To assist research and to ensure that scarce resources are used to answer constraints faced by farmers it is essential to involve all stakeholders in the research process from the inception of a project, and to escape from offering single prescriptions to the building up of 'baskets of options' from which resource-poor, risk-adverse smallholders can select (Chambers et al., 1989). Conroy (2005) explores the processes necessary to achieve sustainable development through participatory research as (1) participatory situation analysis to define the local situation, including the constraints; (2) participatory technology development, which can include both technical innovations and development of livestock packages. Local people are actively involved at all stages rather than coming in at the end as recipients.

However, because of limited resources these approaches cover relatively small numbers of people, leaving successful innovations needing scaling-up. There are also technologies that need moving from the shelf to the field. Garforth (2004) summarises the agents for disseminating them to include: researchers; credit sources; markets; NGOs; extension staff; veterinary services; dealers; shows; school pupils; newspapers; radio programmes; other farmers; farmer organisations. Group meetings with farmers have indicated that the preferred extension pathways are through demonstrations, farm visits and field days. Leaflets are rated as useful when supporting these activities, but of limited value on their own.

It has long been accepted that the number of farmers able and willing to implement a new technique is relatively low: the greater number take up ideas from the experiences of their neighbours, i.e. transfer from 'farmer-to-farmer'. This extension pathway is the basis of the farmer field schools described by Minjauw et al. (2004). Field schools can be run under the auspices of the extension services, NGOS or farmer groups. Millions of farmers in Africa, Asia and South America are now

Table 6
Possible reasons for poor uptake of chemical improvement of the nutritive value of crop residues

	Problem	Comment
1	Cost and availability of urea	Can be acute where urea is imported Competing uses of urea as a fertiliser or a supplementary feed or for treating residues
2	Cost and availability of sealing materials and stores	Plastic sheeting is expensive; but banana leaves topped with soil, or a deep pit with a small surface area are alternatives; also plastic bags (small holes can be taped over). With 1 and 2, stripping of leaves and treatment of refusals only will reduce costs and labour
3	Labour constraints	Grazing of residues *in situ* is often the easiest alternative an it also delivers manure direct to the land; however of feed is scarce this may exacerbate the situation—it also may involve herding or fencing
4	Seasonal variation in feed supply	The greater the dependence on residues, the greater the incentive to upgrade them
5	Cropping areas some distance from the livestock	Inevitably this will increase costs because of transport. The acceptability of this will depend on other feeds available and other outlets for excess residues (e.g. moving livestock to the residues, deals with neighbours) (see also ‘box baling’ and ‘leaf stripping’)
6	Rigid procedures for applying treatment	Most reports describe experimental procedures: on-farm these can be modified to suit the resources available (see Smith, 2002 for an example)
7	Lack of knowledge and training	This procedure is easy to demonstrate-best done on farm using the farmers’ resources. A fact sheet should be available to support the demonstration
8	Benefits are not always obvious	Improved dry season feeding is often only seen as a reduction in live-weight loss (reductions in mortality are difficult to perceive); the gains are likely to include increased survival of progeny and increased reproductive performance, but these often occur outside periods of feed scarcity
9	*Word of caution*	*Treatment usually improves intake and digestibility. If feed supplies are very limited it may be necessary to limit the amount of treated material offered.*

involved in this type of technology transfer (Minjauw et al., 2004).

Measuring innovation uptake is not straightforward. Projects designed to generate technology are rarely funded to go back and assess usage after input support has been withdrawn. Of those projects successfully transferred into practice the following are worthy of note:

1. The community-based dairy goat project in Meru District, Kenya, which is farmer managed through the Meru Goat Breeders Association. The project generates improved dairy goats, based on the Toggenburg and local goats, both for sale and for milk production (Ahuya et al., 2002; www.farmafrica.org.uk).
2. The promotion of the collection and storage of tree fruits as dry season protein supplements. While farmers knew that goats, and other ruminants, ate tree fruits on range, most had not appreciated that they are an easily collectable and cheap feed resource. There was also little information on quantities to feed as supplements (Tanner et al., 1990; Smith et al., 2006).
3. The development of box baling for moving forage from the crop lands around Arusha, Tanzania, to the highland stock keeping areas. By increasing the payload per vehicle it is possible to substantially reduce the cost of transportation (Massawe and Mruttu, 2005).
4. The Mashreq–Maghreb project (M&M, started in 1995 and coordinated by ICARDA) development of integrated crop–livestock production systems in low-rainfall areas of the Mashreq (Iraq, Jordan, Lebanon, Syria) and Maghreb (Algeria, Libya, Morocco, Tunisia) regions promoted a human resources development approach to building the capacity of local populations to plan and manage local development. This project developed and tested technologies (e.g. feed blocks, cactus and fodder shrub plantations), mechanisms, methodologies, and processes, which helped empower communities, by

helping them to face the challenges of living in low-rainfall areas: low productivity, land degradation, drought, desertification, high risk, and uncertainty (El Mourid et al., 2002).

It is also necessary to note those initiatives that have not been as widely adopted as expected, particularly in Africa. Possibly foremost amongst these is the treatment of crop residues because of their importance as a feed resource. Reasons for this have been noted by Owen and Jayasuriya (1989a) and Smith (2002) and are listed in Table 6.

6. Conclusions and recommendations (notes/thoughts)

A battery of interesting technologies have been developed for better use of local feedstuffs (e.g. feed blocks; forage conservation) or to reinforce the feeding programmes of ruminants with novel or less-known feed resources (e.g. cactus, tree fruits). These technologies were in some cases welcomed, but sometimes rejected or slowly adopted by farmers. Some of these technologies have been developed and transfer attempted without the involvement of target users and without an adequate understanding of their farming systems and constraints. Based on encouraging results obtained in some participatory research–development projects, it is clear that involvement of all stakeholders is mandatory for the development of cost-effective and sustainable feeding strategies for animals raised under harsh conditions. This could be achieved whenever the following points are considered:

- Researchers accept to investigate constraints encountered by farmers in the field (e.g. low performances, feed shortage, etc.) and that while concepts should be developed in the laboratory, adaptation into practice should be carried out on-farm.
- Researchers should explore and fully characterize the intervention zone before starting the identification and or development of appropriate solutions and techniques.
- Farmers should be involved in all stages of on-farm research.
- Extension staff (and all relevant groups) should also be involved-problem solving is a team operation in which research is a key, but not the only, factor.
- Where possible farmers should not be 'told' by extension what the solution is but given a basket of options (Campbell et al., 2005, 2006; 'one-size' fits all solutions do not work in practice).
- We must accept that some technologies, such as upgrading of roughages are useful tools in the armoury, but will only be used in 'emergencies'.
- The reasons for non-adoption should be examined-they may mask a non-technical problem, e.g. absence of credit, cultural, etc. Within the research area these problems should emerge at the planning stage, but in upscaling, targeting new areas, then problems may come to light.
- Although much work is directed at the poorest of the poor, these are the people most likely not to own livestock; however, some technologies are labour demanding and can create paid labour. This has happened with tree fruit collection in parts of Kenya, with the manufacture of blocks, and in the establishment of smallholder dairying.
- Links with pioneer projects should be established for better adoption of developed strategies.

Technology is the most important factor which contributes to growth in agricultural productivity. The rate of adoption of a new technology is subject to its profitability and the degree of risk and uncertainty associated with it, and is highly influenced by the capital requirement, agricultural policies, and the socio-economic status of farmers. Producers benefit from the adoption of new technology through opportunities to lower production costs, either by increasing outputs from the same inputs or by maintaining the same output from reduced inputs.

Of the technologies discussed most address the following problems:

- Roughage improvement.
- Forage and agro-industrial by-products conservation.
- Protein supplementation.
- Use of novel feeds.

Of the promising techniques and technologies to alleviate feed shortage in dry areas, it is worth mentioning:

- Feed blocks and pellets based on local agro-industrial by-products.
- Ensiling some agro-industrial by-products alone or with some shrubs species.
- The establishment and targeted utilisation of promising multi-purpose shrubs and trees, like cactus.
- Improvement of crop residues.
- Conservation of forages.

Needed:

- The problems are on-going and need to be kept under review.
- The number of upgraded livestock are increasing – their production levels should be higher than the animals they replace – this demands better feeding and management.
- Novel feeds.
- Marketing-relaying of information, meeting quality standards, etc. The market place is global; the smallholder must aim at his niche within it.
- Urban agriculture has the added problems of public health and safety-zoonoses.
- Increased productivity from smallholder-owned livestock based on increased levels of inputs will require access to credit.

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