The potential of grassland and associated forages to produce fibre, biomass, energy or other feedstocks for non-food and other sectors: new uses for a global resource

M.F. Askew
Head of Agricultural and Rural Strategy, Central Science Laboratory, Sand Hutton, York, YO41 1LZ, UK
Email: m.askew@csl.gov.uk

Key points

1. In developed countries increased areas of land will become available for non-food production. Recent reforms of the Common Agricultural Policy will further intensify this trend in Europe.
2. There is potential for grassland and associated species to contribute to large tonnage markets of energy and bulk fibres, to the supply of fermentation products and to speciality markets, but processes and approaches to the market are not as yet developed.
3. There is potential for the establishment of *Graminaceous* species - specifically for non-food use. For European conditions particular attention is being given to *Miscanthus sinensis* (Miscanthus), *Arundo donax* (Giant Reed), *Phalaris arundinacea* (Reed Canary Grass) and *Spartina* spp. (Cord grass, Marsh Grass).
4. Whilst grass and forage species could be used for individual non-food uses (e.g. biomass for energy), value may be added by adopting a biorefinery approach in which a range of products are derived from the different components in the feedstock.

Keywords: grassland, non-food, climate change

Introduction

"Grassland covers some two thirds of the total agricultural land area of the earth. Its potential annual dry matter yield is at about 40 billion tonnes per annum but its yield is less than a third of that. There is, therefore, ample scope for grassland improvement and development activities.

Food shortage is one of the most serious problems of the present time in the developing countries and there is little possibility of increasing grain production through clearing new lands. Some 50 million tonnes of grain, 40% of the grain production of the world, is used as animal feed. This illustrates the enormous potential for increasing food supply through replacing feed grains by increased pasture production." (F. Riveros, undated).

In developed countries the position is quite different, grasslands are broadly categorised into grazing, conservation and amenity/sports foci. However, because of wider changes that are occurring (or will occur) in the future, these definitions are no longer appropriate for the exploitation of grassland. Rather, there will be an increasing emphasis on the integration of land use, whereby the provision of feed and feedstocks for non-food use and public good occurs simultaneously. This approach will lead to a more sustainable outcome (i.e. economic viability, and environmental/social/cultural acceptability). The rate at which this change will occur will vary politically and geographically, with areas like EU-25 being early adopters.

Whilst this paper is written primarily in the context of Northwest European agriculture, horticulture and wider land use, its content is indicative of the needs and outcomes for many other areas globally.

In developed and relatively densely populated areas as occur in Northwest Europe; surplus land (i.e. surplus relative to food production) is likely to go into integrated production of non-food crops; amenity and environment-ameliorating activities. Such a trend would offer new opportunities for grassland species.

Environment ameliorating activities

Requirements to ameliorate/prevent environmental ‘decline’ or improve the wider environment fall into the sector of public-good. Their impact can be enormous, but because such activities cover larger areas of land than occur on one holding or interact with other policies (e.g. water management, erosion control, biodiversity etc.), they are difficult for an individual business to influence or manage, and difficult to quantify in terms of financial cost: benefit. However, in some instances the economists’ methodologies of Contingent Valuation may be valuable indicators.

Environment-ameliorating activities impinge considerably at the international level. Significant recent developments include the Kyoto Agreement (UNFCCC, 1997) and the United Nations Convention on Biological diversity (UNEP, 1992). Both treaties offer considerable opportunities for grassland and forages to be expanded as a means of ameliorating global warming and promoting environmental goods and biodiversity.

Non-food uses of forage species

Non-food uses of plants are not new, but with the exception of species like *Gossypium hirsutum* (cotton), *Hevea brasiliensis* (rubber) and *Elaeis* spp. (oil palm), have not in recent years been internationally exploited - especially in cool temperate areas. Much of this under-exploitation may be attributable to the availability of fossil oil-derived feedstocks, which have advantages of known technology, price and uniformity of feedstock. It is to be noted however that starch, from many diverse sources, is a major international food and non-food feedstock.

For grassland and other forage species to reach similar levels of knowledge and commercial exploitation will take time. Nonetheless, evidence from related species like *Triticum aestivum* (wheat) offers an indication of potential that may be exploited in preparation of non-food products.

A large number of metabolites have been identified in common UK tree species. These were catalogued by Central Science Laboratory; http://treechemicals.csl.gov.uk/review/index.cfm.

Hitherto such market opportunities were unexploited. However the position is less well documented with many forage grasses. This aspect needs action if value is to be added to forages through simple extraction or biorefining technologies. It seems likely that biorefining will be a key component of exploitation of sustainable biomass in the future since it allows fullest economic exploitation of biomass.

Current markets for forages in the non food sector

Current markets (or those close to exploitation) fall into 2 categories; 1) large tonnage commodity markets for production of energy or bulk fibre, or 2) using forage crops as a feedstock for fermentation, and speciality markets using grasses like *Nandina* spp. (bamboo) for added-value fashion fibres (in Europe) or building (in Asia), or Miscanthus for plant pots.

Evidence reported recently (Askew, 2001) indicated anticipated growth patterns, on a global scale, for all biorenewables. These estimates, which at that time excluded primary energy and biorefining markets, are shown in Tables 1 and 2.

Table 1 Production of crop derived raw materials for industrial use – million tonnes[1]

	Europe	USA	Global
Vegetable oils[2]	2.6	3.0	12.5
Starch	2.4	6.5	15.0
Non-wood fibres	0.5	3.0	23.4
Total	5.5	12.5	50.9

Source: IENICA Report UK (2000); [1]1998 Figures; [2]Practical applications (palm oil = soap; starche = paper industry; fibres = paper industry).

Table 2 Anticipated growth: production of crop derived products - million tonnes

	Global output 1998	Global output 2003	% growth
Vegetable oils[1]	12.5	19.8	58
Starch[2]	15.0	22.5	50
Non-wood fibres[3]	23.4	28.4	21
Total	50.9	70.7	38.9

Source: IENICA Report UK (2000); [1]Vegetable Oils (projection based on forecast for EU growth - Source: FEDIOL, 2000); [2]Starch (projection based on forecast EU growth - Source: National Starch, 2000); [3]Non-wood fibres (projection based on Paper Industry Research Association (Pira) global forecast for pulp and paper use combined with EU figures for non-wood fibre production).

Biomass for energy

Energy is currently a key interest area. This is due to the impact of changes in global atmosphere as reflected in the recently ratified Kyoto Agreement, and drivers for renewable energy e.g. EU White Paper on renewable energy, (White Paper for a Community Strategy and Action Plan) which identifies 135 million tonnes oil equivalent as the contribution of biomass to energy generation for heat and electricity in the former EU15 by 2010 (Tables 3 and 4), and the EU legislation on biofuels (EU Biofuels Directive, 2003) which projects an increasing contribution to substitution of fossil-oil derived gasoline and diesel oil (projections stand at 20% by 2020).

Table 3 Current and projected extent of renewable energy sources in EU-15

Type of energy	Energy units	Share in the EU in 1995	Projected share by 2010
Biomass	Mtoe[1]	44.8	135
Geothermal			
Electric	GW	0.5	1
Heat (incl. heat pumps)	GWTH[2]	1.3	5
Hydro	GW	92	105
Large	GW	82.5	91
Small	GW	9.5	14
Passive solar	mtoe	35	
Photovoltaics	GWp[3]	0.03	3
Solar thermal collectors	million m²	6.5	100
Wind	GW[4]	2.5	40
Other	GW	1	

Source: EU, (1997); [1]Mtoe = million tonne oil equivalent; [2]GWTH = giga watt thermal; [3]GWp ; giga watt photo; [4]GW = giga watt

Table 4 Current and projected contribution of renewable sources of energy to electricity generation in EU 15

Type of energy	Actual in 1995		Projected for 2010	
	TWh[1]	% of total	TWh	% of total
Total	2,366		2,870	
Wind	4	0.2	80	2.8
Total hydro	307	13	355	12.4
Large (including pumped storage)		(270)		(300)
Small		(37)		(55)
Photovoltaics	0.03	-	3	0.1
Biomass	22.5	0.95	230	8
Geothermal	3.5	0.15	7	0.2
Total renewable energies	337	14.3	675	23.5

Source: EU (1997); [1]TWh = Terrawatt hrs

Considerable emphasis has been laid on the development of *Miscanthus* spp. This is commonly, but incorrectly, called Elephant Grass. The primary market has been for production of electricity/combined with heat and power, although secondary markets, such as manufacture of plant pots, are being developed. In terms of the wider exploitation of this plant, an integration of uses needs to be achieved in order to optimise growers' financial returns - energy may not offer the most profitable market (Table 5). This probably summarises the position for most forages.

Biomass for liquid fuels

Feedstocks for gasoline replacement could be sugar (sucrose) or starch-derived, but are more likely to be derived from low value cellulosic materials, e.g. cereal straw in the immediate future (technology exists with the IOGEN company in USA at present). Whilst current technologies to produce diesel replacements from biomass are heavily focussed upon esterification of vegetable oils (e.g. rapeseed oil), it seems likely that the next generation of bio-diesel will be developed from pyrolysis of plants or animal wastes, producing a bio-oil, which could then be refined. Gasification may offer opportunities too.

Table 5 Alternative markets for *Miscanthus* spp. at a standard dry matter

Base price for *Miscanthus* spp. intended for;	£/tonne
Power generation	20-40
Equine bedding	45-70
Bagged equine bedding	160-200
Organic straw	70
Industrial fibres and composites	70

Source: D.B. Turley (*pers. comm.*)

Markets for liquid fuels are extensive and it seems unlikely that land-based industry in its totality could produce enough feedstock to satisfy them totally. Nonetheless, feedstocks from land-based industry could form an integral part of a broader feedstock stream, which would include urban/municipal and other wastes.

Examples of current potential for bioethanol production are given in Table 6. Bioethanol provides a substitute fuel for gasoline. Usage varies but will begin at or about 5% volume/volume level in Europe.

Table 6 Tonnes of feedstock crop required to produce 1 tonne of bioethanol and typical yields of bioethanol per hectare of feedstock crop

Ethanol feedstock (typical field yield)	Feedstock requirement per tonne of ethanol produced (tonne)	Estimated ethanol yield from typical UK crops (kg/ha per year)
Starch crops		
Potatoes (40 t/ha)	11[a]	3600
Wheat (8 t/ha)	2.5-3.0[a]	2600 - 3200
Sugar crops		
Sugar beet (53 t/ha)	11-12.5[a]	4240- 4818
Lignocellulosic		
Grown		
SRC* (32-35 odt/ha)	5.5-7.5[b]	1,200-1,650
Miscanthus spp. (10-12 t/ha)	5.5-7.5[c]	1,400-2,000
Waste or co-product		
Hardwood	5.5-7.5[b]	5-6
Softwood	6.25-9.75[b]	3-5
Straw	4.25-6.25[b]	750-1050

*SRC = Short Rotation Coppice is harvested every 4 years; the yield indicates the equivalent annual ethanol production potential per hectare. Source: [a]derived from Marrow *et al*. (1987); [b]derived from Marrow & Coombs (1990); [c]estimated based on material composition (Turley *et al.*, 2005)

Other biomass uses: Biogas

Anaerobic digestion is a further area where a range of feedstocks from land-based industry may provide energy. This process has been used on graminaceous species in the past and currently new projects like "Greenfinch" in UK are testing potential. The essence of such processes is shown in Figure 1.

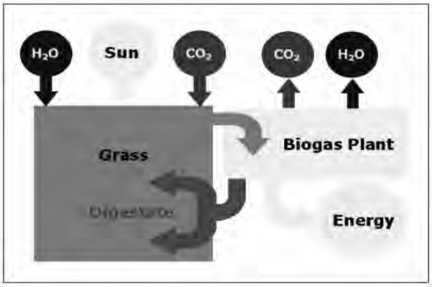

Figure 1 Anaerobic digestion of grass (Source: www.greenfinch.co.uk)

Promotional information provided by FNR in Germany (Fachagentur Nachwachsende Rohstoffe, 2004) indicated potential production of biogas from ensiled forages (Table 7). However, at present most interest in anaerobic digestion is focussed upon animal wastes.

Table 7 Potential production of biogas from ensiled forages

	Tonnes required to produce		
	55kw	330kw	500kw
Grass silage	400	1500	-
Maize silage	600	2500	1700

Source: FNR (2004)

Grass (2004) reported on a pilot unit in Switzerland intended to integrate biorefining and anaerobic digestion. The Schaffhausen installation was found not to be economically viable and the operation was stopped in summer 2003. Production-related reasons for the failure include low revenues from product sales (blow-in insulation) and the unsatisfactory performance of some plant components (e.g. fibre drying and packaging).

The plant produced fibreboard insulation, fibres and biogas from grass, for use in technical applications. Innovations regarding raw material fractionation, production of biogas in the UASB reactor, and grass washing were demonstrated successfully. Technical fibres were further processed on-site for production of a 'blow-in' insulation product marketed under the brand name *2B Gratec*. Certification and market introduction of *2B Gratec* was successful. Biogas was utilised in a combined heat and power plant. Heat was used internally for drying the fibres.

The power was certified and marketed under the label 'Nature Made Star'. The plant had a raw material throughput capacity around 0.8 t DM/h. The yield of *2B Gratec* was 500-600 kg/t DM and the biogas yield was 150-250 m^3 at around 6 kWh/m^3, depending on raw material quality. Relative costs and values of inputs and products are shown in Table 8.

Table 8 Product attractiveness

	Investment cost	Yield	Value added	Large-scale product marketing	Overall attractiveness
Fibre insulation boards	High	High	High	Possible	High
Fibre blow-in insulation	High	High	Medium	Difficult	Medium
Grass juice for animal feed	Low	High	Low	Possible*	Medium
Dried protein for animal feed	High	Medium	Medium	Easy	Low
Biogas/energy	High	Medium	Low	Easy	Low

*In small-scale production units. Source: Grass (2004)

Grass (2004), concluded that:
- Wet fractionation of grass is a powerful tool for the generation of added value from several products;
- Insulation boards combine high yield with high added value and appear as the most attractive of the products examined;
- Production of ethanol, biogas and power is cost-intensive and contributes little to the overall economics of a biorefinery;
- Linking two or more expensive new production lines results in the spreading of risks and should be avoided.

Whilst the potential market for fibres in textiles is enormous and increasing, emphasis is on polyester and cotton (IENICA, 2000).

Further, estimates for the automobile industry in EU show considerable potential to replace fibreglass with plant fibre: currently this is sourced from hemp or flax. Whether or not fibre from forage species could substitute has not been reported.

A note on some individual *Graminaceous* species under development for the non-food sector

Miscanthus sinensis (Miscanthus)

Miscanthus is a perennial graminaceous crop, growing up to 4m in height under European conditions. 'Life expectancy' can be up to 20 years. Dry matter yields vary according to location but can reach 15 t DM/annum.

Key agronomic aspects of production are:
- Not suited to drier/drought areas;
- Currently propagated by rhizomes – c. 20,000/ha;
- Weed control in the establishment phase is essential.

Arundo donax (Giant Reed)

Arundo donax (also sometimes referred to as Giant Cane, Wild Cane, Common Reed, Spanish Reed, False Bamboo or Dumb Cane) is native to south-eastern Europe, and so is already adapted to EU agro-climatic conditions. It is quite common in the Mediterranean where it occurs wild in marshy areas or by rivers. It is often planted as a windbreak at the edges of cultivated fields, on the banks of dykes etc., and can help maintain soil structure in these situations due to the abundant root system. Stems are stiff, smooth and hollow, usually around 5 cm thick, growing up to a height of 6m. The pointed leaves are greyish-green and usually 2-5 cm wide and up to 30 cm long. *Arundo donax* flowers infrequently in late summer with purple-brown flower heads borne in long, dense, plume like panicles.

The fibre produced by the crop is of high quality and has a long, thin structure making it suitable for a wide variety of uses (Table 9). In suitable conditions it has been shown to be a potentially prolific producer of biomass, capable of yielding up to 34 t DM/ha per annum for several years. However, it usually takes 3-5 years to reach its full biomass production. *Arundo donax* can tolerate severe drought conditions (yields of up to 19t DM/ha can still be achieved), and is generally found in warmer and drier regions than other reeds. Thus it appears to be more economical and environmentally favourable to grow under moderate irrigation without dramatically reduced yields.

Arundo donax can either be harvested annually or biannually depending on production expectations and growing conditions. Seed viability is currently unknown but it is clear that the crop requires replanting every 25-120 + years to maintain productivity. Unlike some novel crops, mechanical means are available for both planting and harvest of *Arundo donax*. However, two main problems arise when growing the crop; I) the interconnecting root mats form debris dams in rivers and increase the risk of flooding; ii) the crop ignites easily and can cause intense fires if not controlled with care. The requirements for fertilisers on the crop are also low due to the dry leaves returning to the soil enriching it with organic matter.

Table 9 Potential non-food uses for *Arundo donax* (Giant Reed)

Pipe organs
Basketry
Fishing rods
Pharmaceuticals
Soil erosion control
Industrial cellulose
Pulp, paper
Feedstock for electrical energy
Panels, flooring, beams

Few pests have been reported on *Arundo donax*, and so the requirement for pesticides is negligible in most cases. The crop also appeals to many growers due to the low agrochemical inputs required; this is also beneficial to the environment. Whilst there is currently an absence of demand for products from *Arundo donax*, the crop has not yet become domesticated. However it does have potential in a number of non-food market sectors (Table 9).

Phalaris arundinacea (Reed Canary Grass)

Phalaris arundinacea is a robust coarse perennial, widely distributed across temperate regions of Europe, Asia and North America. It grows to between 0.6–2.0 m high, and has hairless light green or whitish green leaves 10-35 cm long and 6-18 cm wide. Flowering occurs in June to August, and seed is produced. *Phalaris arundinacea* spreads naturally by creeping rhizomes, but plants can be raised from seed. The plant frequently occurs in wet places, along the margins of rivers, streams, lakes and pools.

Until the mid 1950s *Phalaris arundinacea* grew wild and received little scientific or commercial attention. Researchers then noticed that the plant possessed two desirable characteristics: the ability to withstand drought and conversely excessive precipitation.

More recently, the species is being evaluated in Sweden as a fibre and energy-producing crop, where there is a breeding programme evaluating *Phalaris arundinacea* grass as a potential source for fibre from pulping and for fuel. Current production and yields are shown in Table 10. (NB uses of crop vary in this data).

Table 10 Current production and yields of *Phalaris arundinacea* (Reed Canary Grass)[1]

Area	Number of cuts	Yield t DM/ha
USA	3	11
USA	1	4.4-8.6
Canada	3	9.5 – 12
Sweden	2	10
UK	1	4

[1]uses of crop vary in this data. Source: Chisholm (1994)

Spartina spp. (Cord Grass/Marsh Grass)

Spartina pectinata and *S. cynosuroides* occur naturally in western Europe, North America and Africa. *Spartina cynosuroides* is found on salt or brackish marshes from Massachusetts through Florida to Texas, and *S. pectinata* on marsh shores or wet prairies from as far north as Newfoundland through the prairie states as far south as Texas (Gleason, 1952). They are related to the native esturine species *S. anglica* and *maritima*. *Spartina* spp. spread by means of scaly creeping rhizomes to form clumps and mats.

All species are C4 pathway species and have higher carbon assimilation rates than C3 forage grasses, and are more efficient interceptors of radiation receipts. They also have a significantly higher uptake of CO_2 and are less sensitive to chilling than annual C4 species. The yield potential of these grasses may exceed 10-15 t DM/ha.

Spartina pectinata and *cynosuroides* have been shown to be adaptable to a range of growing conditions and to produce higher yields than most natural grasses with a low input of fertiliser. However yields are lower than seem possible from other biomass crops such as *Miscanthus.* The advantage of these species is their potential to be established from seed, their greater adaptability to adverse soil conditions, low fertiliser requirement and their higher dry matter content earlier in the winter. It is likely that these species will be well suited to mild wet climate areas in Europe.

Reform of Common Agricultural Policy (CAP): an example of a new scenario

The Common Agricultural Policy of the European Community (EU-25) applies to all member states (though when initial accession occurs there is usually an adoption period of several years). To a great extent therefore the following comments relate to the established 15 states in the EU.

CAP had the intention of ‘providing farmers with a reasonable income’. This was achieved originally via market intervention and direct aids on many, but not all agricultural/horticultural products. However since 1992 focus has changed, initially to area or headage payments related directly to production, and more recently to decoupled single farm payments (SFP). The two most recent reviews of CAP were Agenda 2000 and the 2003 Reform (sometimes called Mid Term Review). These two reforms have begun the transition from production-orientated agriculture (Pillar 1) to a focus on provision of public goods in the environmental sector (Pillar 2).

Provided that cross-compliance measures are met then each agricultural holding will receive a SFP. Clearly the SFP allows a holding to remain viable, but does not necessarily demand agricultural/horticultural production in the traditional sense. Hence ‘profitability’ of individual enterprises will change radically. This will be reflected in the upland grazing situation in particular. Data from PROMAR (2004) summarised the situation; they suggest a severe downward readjustment in livestock numbers as decoupling occurs due to significant reduction in profitability.

From this it is clear that an individual must add value to his/her grazing livestock production, support the enterprise financially from other resources, or reduce or abandon the enterprise entirely. This situation demands new approaches and thinking in terms of forage grazing utilisation. At the same time, the speciality root crops - sugar beet and potatoes appear likely to decline in area, the former because of revision of the EU Sugar Regime. Areas of potato production are declining in EU, as a reflection of increased yield and static or declining demand. Hence, there is the opportunity for additional areas of land to be released for new uses, provided that sustainable alternatives can be characterised. It will be essential that this land is managed rather than abandoned; grass species probably offer the best utilisation option.

Output needs focus

Whilst development of sustainable markets for feedstocks from graminaceous and related forage species appear to have potential, they must be able to compete economically in the marketplace. Hitherto each outlet for bio-renewables has been developed in isolation; some markets may be more viable than others. Unfortunately no integration of production has been undertaken: wheat straw could be burned for heat and power, fermented to produce bioethanol to replace gasoline or used to make paper. It would appear logical that a similar situation will occur with some non-specialist products from grasses.

Ways forward

The key elements for progress are:

- Identify and prioritise opportunities – especially markets currently in production or otherwise;
- Identify and prioritise forages as feedstocks linked to top priority opportunities;
- Develop integrated sustainable production and utilisation procedures for forages.

Conclusions

Experimental evidence and scientific/technical practice have confirmed the potential of many species of plants as feedstocks for non-food products. Amongst the *Gramineae*, progress has been relatively limited with only a small number of species being exploited. Whilst there must be considerable emphasis on food production in many parts of the world (especially Asia and Africa), new policies and direction in more economically developed areas like EU-25 or North America are offering new opportunities. However in terms of the forage grasses and associated dicotyledonous species little direct progress has been made and a radical new strategy to develop forage grasses *et al.*in a sustainable environment in the absence of livestock is required.

Acknowledgments

The author is pleased to acknowledge the assistance of Mrs Denise Beardall in the typing of many drafts of this paper, also assistance from colleagues in Agricultural and Rural Strategy Group of CSL in sourcing data.

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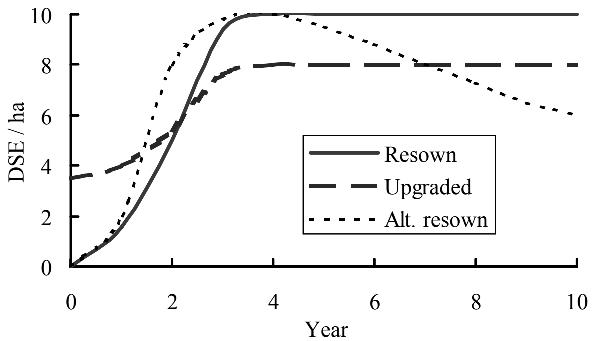

Figure 1 Modelled patterns in stocking rates (DSE: dry sheep equivalents) for grasslands managed to a more productive state (upgraded) or resown. The alternative resown pattern may be more typical of the region. Data are for an average area in central NSW (D.R. Kemp, *unpublished*)

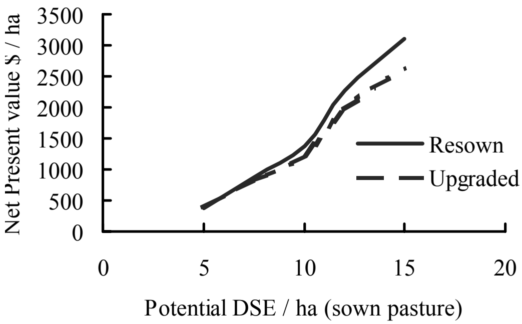

Figure 2 Net present value of alternative grassland management strategies over a ten-year period (D.R. Kemp, *unpublished data*). The 'upgraded' grassland is stocked at 80% of the sown

However, if the alternative (and more common scenario) is considered, i.e. that productivity in the region tends to decline over time (Figure 1; alternative resown pathway), the economics are worse (data not shown). This leads to the general conclusion that the most appropriate pathways for development and improved environmental outcomes arise from (conservative) grazing management - designed to retain the perennial species that are often lost, as opposed to resowing (Dowling *et al*., 2001). The key point is that focus needs to be on net farm profits over the long-term rather than physical output or gross income. Much of the literature seems to ignore these criteria.

Revisiting concepts for productive versus sustainable grassland systems

There are often two general views of farming systems. The **first** view is that a 'factory' approach is sufficient where resources are put in one end of a pipe and products extracted at the other. In the 19th century J. von Liebig developed the concept of the 'law of the minimum' i.e. one factor is usually limiting production at any one point in space and, or time. That 'law' has helped develop the 'factory' view, but is it conceptually useful for more sustainable systems? In this mindset the focus is often only on a limited number of components, with