SESSION 6C

NOVEL AND INDUSTRIAL CROPS: REALISING THEIR POTENTIAL

Chairman:	Melvyn Askew *Central Science Laboratory, York, UK*
Session Organiser:	David Turley *Central Science Laboratory, York, UK*
Papers:	6C-1 to 6C-4

An overview of opportunities and factors affecting exploitation of crops for industrial use

M F Askew
Central Science Laboratory, York, North Yorkshire, YO41 1LZ, UK
Email: m.askew@csl.gov.uk

ABSTRACT

The exploitation of products from plants is not new but went into decline as synthetic materials were developed from coal and oil and technological development meant that animals were outclassed as primary sources of traction. The recognition of the need for true sustainability, led by concerns over the impacts of current farming practices and the impacts of our industrialised society on pollution and global climate change, has caused a revision of views. Significant markets for sustainable biorenewable raw materials now exist, created by legislative change or by technical or economic advantage. Nonetheless progress in uptake has been slow for a number of reasons and aspirations to achieve targets for increased use of renewable raw materials may prove difficult to fulfil. Some of the reasons for this are discussed.

INTRODUCTION

The production of non-food products from plants and animals is not new but has changed due to introduction of novel technologies, availability of raw materials/feedstocks and public demand. Examples occur in the energy, oils and fibres sectors. Prior to the introduction of internal combustion engines most power came from draught horses or oxen which were fed biorenewable energy as oats, other cereals, forages or proteins like Faba beans. Similarly the utilisation of fibres from plants like hemp, flax and jute provided ropes, canvases and a range of other products, whilst animal and vegetable oils and fats provided lubrication and a basis for lighting. Most of these non-food crop uses were superseded by the exploitation of fossil coal and oil resources. With a move towards a demand for use of more sustainable raw materials (in terms of their economic impact, environmental performance/impact and cultural/ social acceptance) the pendulum is moving back again to biobased materials. There have been considerable technological developments in the biofeedstocks sector such that many sustainable products can have as good a technical performance as synthetic materials and in some recent cases (e.g. in-car composite panels) could be superior to existing synthetically derived products.

For the successful development of such opportunities there is a need to link raw material markets with processing and production industries and to provide appropriate underpinning support. This can be characterised as shown in Figure 1, taken from a recent United States roadmap for the planed future development of the US non-food crop sector.

Realistically, for the continued and desirable exploitation of sustainable biorenewable feedstocks and products four fundamental questions have to be asked. In tackling responses to these questions it has to be recognised that a fundamentally new appreciation of the crops or animal species in question may be essential to fully exploit all possible opportunities.

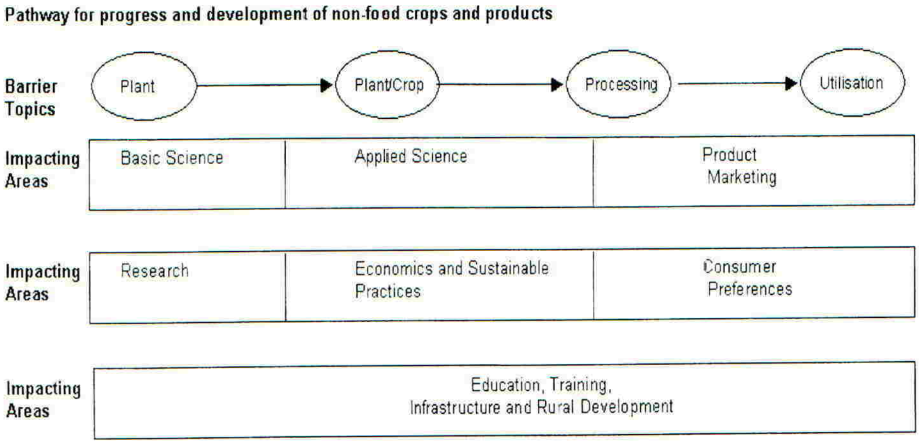


Figure 1. Pathway for progress and development of non-food crops and products.

The fundamental questions are:

Is there an awareness of the potential for land-based industries to produce diverse biorenewable products?

Is there a strategic view on how biorenewables should be developed? If so why is progress slow?

How should sustainability be considered?

How can the diverse needs of individual production/utilisation chains be identified, characterised & integrated?

Considerable markets for products from plants or at least some of their components already exist, as exploited on a large scale in the food sector. But a fundamental re-appraisal of potential plant products reveals a much wider range of opportunities especially in the non-food sector. An example of the potential range of products that could be derived from wheat via a number of, and in some cases complimentary, pathways is shown in Figure 2.

Similar opportunities have been identified in the fibre and oleaginous plant sectors. Good examples include hemp, which has numerous realised and unrealised market outlets for both vegetative and oil based plant components, and castor bean, where a wide range of materials can be derived from modification and further processing of this valuable tropical oil. For long term sustainability the way forward must be to exploit such opportunities concurrently, using a whole plant products approach.

Drivers for Change

A number of diverse drivers stimulating change to renewable raw materials exist. Some are inter-related and complementary although this is not always the case. These include:

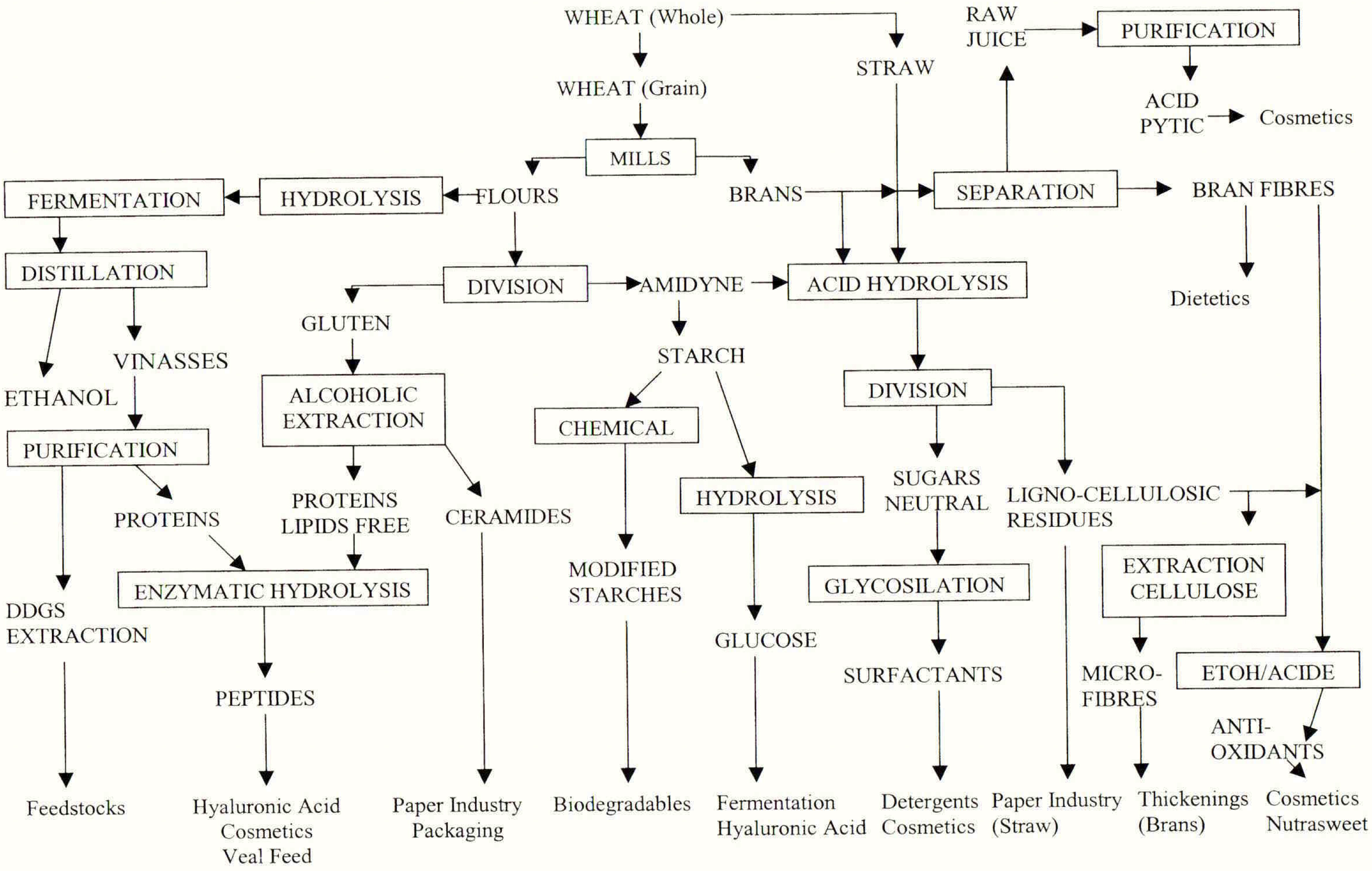


Figure 2. Potential range of products and feedstocks that can be derived from Wheat

- sustainability of agriculture, the rural economy and industry at large
- environmental protection and mitigation of global warming
- legislation and cost of non-compliance for industry
- public opinion
- international agreements of various types but with the common resolution of demanding renewable sustainable feedstocks e.g. Kyoto; WTO discussions

One major area needing radical action is that of global warming and the need to reduce green house gas (GHG) emissions. One means of tackling this is through the development of, and change to, carbon-sequestering and CO_2-neutral technologies.

Examples are shown in Table 1 of the extent of diminution in GHG accumulation that could occur through the exploitation of sustainable biorenewable resources in a number of market sectors.

Table 1. Examples of potential primary savings in greenhouse gas emissions (CO_2 equivalents) that could be achieved through substitution by renewable raw materials.

	Current market penetration (%)	Current savings in GHG emissions ('000 tonnes)	Approx. total potential market penetration (%)	Approx. total potential saving in GHG emissions ('000 tonnes)
Polymers	0.15	100	1	600
Lubricants	2	200	20	2000
Solvents	1.5		12.5	1000
Surfactants	20*	1700	50-100***	2000
Total GHG savings:		2000		5600**

* Of which 16% derived from vegetable oils and 4% from animal oils and fats.

** Corresponds to approx 1.5% of the EU Kyoto commitments.

*** This is an over-estimation of today's technical potential, but represents what possibly could be achieved over a longer time perspective (for GHG savings, a more conservative market penetration potential has been used).

Other drivers stimulating uptake of renewable raw materials and feedstocks include EU Directives (e.g. the banning of volatile organic carbons (volatile solvents) under health and safety legislation; the banning of inclusion of used vegetable oils in animal feedstuffs; moves to reduce packaging and encourage use of more biodegradable degradable packaging through the EU packaging directive; development of EU energy policies for renewable energy sources and targets for renewable energy generation).

Given recognition of the need to re-develop sustainable biorenewable feedstocks, and the various direct and indirect political and legislative procedures that exist as drivers, the slow rates of change and uptake by industry is disappointing.

Change and Future Progress

It is now generally recognised, especially in EC circles, that rate of change needs to be accelerated. Despite the EC having funded R&D to the extent of 160 millions of euros over the last 10 years, the current "technology push" has not secured an adequate rate of progress. A number of issues have been identified as hampering the rate of uptake of sustainable biorenewables. These include; lack of awareness of opportunities within industry, lack of financial need or incentive to change, investment in current technologies and lack of capital to re-tool, lack of clarity in the development of the non-food renewables market in political and environmental sectors, lack of market organisation and guaranteed supply of primary products in the quantities and quality required.

Markets

One fundamental question is that of markets: do real markets exist for sustainable biorenewables and if so what are the opportunities and the potential for growth and development ?

Markets exist in two types; the large commodity market, where the feedstock supplier has little control over price, and the small, high value market. In the latter, the primary producer can add value through exclusive contracts and partial or total vertical integration of the business into the sector. At a basic level, added value can be achieved by undertaking primary processing etc or by cooperating to co-ordinate supply and oversee quality etc.

The IENICA project, funded by DG Research of EC undertook ground breaking studies of potential markets for sustainable biorenewables for EU 15 during the period 1997-2000. Current work is assessing the potential of Eastern European and other markets. Considerable market opportunity was identified. Markets for renewable raw materials were divided into several broad groups: oils, fibres, carbohydrates and speciality products. For the sake of brevity a résumé of the key findings only is given below; full details are available on the world wide web at www.ienica.net. Based on industrial applications, further groupings can be made e.g. lubricants, solvents, surfactants etc. The diversity of renewable raw material sources and products can in itself be a barrier to development by hampering focussed attention within the sector.

Oils

Overall usage of vegetable oils and animal fats in the non-food sector of EU-15 is estimated at approximately 3 million tonnes per annum (excluding biofuels). Key potential EU market volumes for substitution by renewables are: bio-lubricants (370,000 tonnes/annum), bio-printing inks (in excess of 120,000 tonnes/annum) and bio-solvents (approximately 0.5 million tonnes/annum). Only a fraction of these potential markets have been realised to date. There are also opportunities to expand use in the polymer sector, particularly for erucamide derived from High Erucic Acid Rape and Crambe.

Fibres

There are opportunities for EU produced fibres to substitute for imported natural fibres (e.g. jute and kenaf). There are limited opportunities for use in the textile market and most of these will be small niche areas. There are significant opportunities in the technical fibre market. The car and aircraft industry is currently driving demand for fibres for bio-composite production and the potential European market could be as high as 350,000 tonnes per annum of fibre, which represents a demand for 1 million tonnes of raw product. There could be further opportunities in the building industry and for insulation but theses markets will need further development.

Carbohydrates

Starch markets in the EU and elsewhere are well developed and organised. 3.7 million tonnes is used in the non-food sector; 1.4 million tonnes in paper and cardboard making, 1.1 million tonnes in plastics and detergents and 1.2 million tonnes in fermentation and other technical uses. There are also opportunities for small high value niche markets such as cosmetics and pharmaceuticals.

Speciality Products

These offer considerable potential for high value, low volume products. However such markets are volatile and subject to commercial sensitivity. Essential oils markets world-wide ammount to approximately 45,000 tonnes per annum and aromatic plants have a world market of greater than 50,000 tonnes per annum. The European herbal supplements market is valued in excess of €7 billion per annum.

Energy

EC/EU energy policies for development of renewable sources of energy are now in place and being developed in practice. The UK Government Policy White Paper "Our Energy Future – Creating a Low Carbon Economy" was published during February 2003 and states the UK's aim of tackling global warming and increasing fuel security while maintaining affordable energy for all. The UK plans to achieve a 60% reduction in its carbon dioxide emissions by 2050, this will have a significant impact on the uptake of renewable raw materials.

CONCLUSION

Without doubt, scientific and technological developments have progressed to an extent which currently permits the widescale exploitation of biorenewable products. However, some key areas are still hampering exploitation including;

- Lack of political and administrative co-ordination of effort
- Lack of awareness of opportunities in all sectors of industry
- Full assessment of environmental benefits compared to fossil-derived alternatives
- Focussed technology transfer to stimulate development
- Market structuring to support development

Issues affecting development of non-food crops – an industry view

C Spencer
Springdale Crop Synergies Ltd, Springdale Farm, Rudston, Driffield, East Yorkshire, YO25 4DJ, UK
Email: info@springdale-group.com

ABSTRACT

In recent years there has been significant and growing interest in the production of non food crops and their derivatives; examples include specialist oilseeds, fibre crops, natural dyes and energy crops. To date, the commercial uptake of such crops has been relatively limited and this paper aims to provide an insight into why this is and how such obstacles have been overcome in a number of cases to create a dynamic and expanding range of commercial non-food crops. Commercialization of crambe (*Crambe abyssinica*) otherwise known as Abyssinian mustard in the UK, is used as an example case study, building from initial research and development through to field production of over 3500 ha within 3 years, with plans for a significant increase in 2004 and beyond. The contents of this paper are derived from both practical and commercial first hand experiences in developing a wide range of oilseed, fibre and energy crops from initial conception through to full establishment of viable markets.

INTRODUCTION

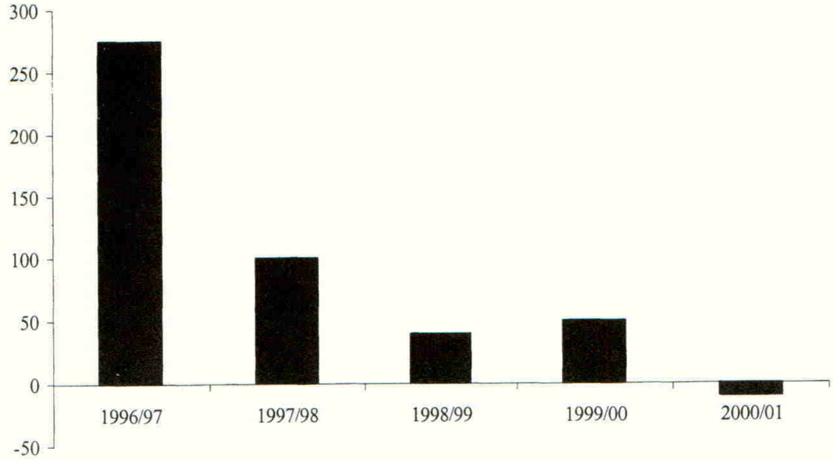
For a variety of reasons discussed below, there has been increasing interest amongst primary producers in moving away from food crop production and towards production of non-food and industrial raw materials.

Commodity prices

The recent significant reductions in commodity prices, for example the price of UK feed wheat falling from approximately £120/tonne ex farm in 1996 to approximately £80/tonne ex farm in September 2003, with no corresponding reduction in input costs has resulted in declining farm incomes (Figure 1). There is a desperate need to find means of boosting farm profitability and of diversifying sources of income.

Legislation

There is a strengthening "green" environmental lobby, plus other EU legislation affecting areas such as use of volatile organic carbon compounds and control of emission of 'greenhouse gases', which is stimulating industry interest in use of renewable raw materials. Both growers and manufacturing industry are subject to close scrutiny regarding justification for use of inputs and for any environmental impacts associated with output. International agreements such as those agreed under the Kyoto protocol to reduce greenhouse gas emissions have a significant effect on government policy and its impact on stimulation of renewable raw materials for industry and energy production.



Source: Auborn, Deloitte & Touche, HGCA

Figure 1. Falling farm incomes in the UK, 1996 – 2001 (£/ha)

Energy

It is increasingly recognized that fossil fuel supplies are limited. At current levels of demand, conventional oil supplies are expected to last up until around 2040. The UK will become a net importer of gas and oil by 2010 according to industry estimates. There is a need to develop renewable energy supplies to ease pressure on fossil fuel stocks and secure energy supplies. The recent Iraq conflict highlights the UK's susceptibility to severe fluctuations in price and its reliance on other countries. Home grown sources of liquid biofuels include biodiesel and bioethanol and biomass crops can be used for electricity generation.

Consumer demand

There is an increasing awareness of health issues and an associated increasing consumer demand for products derived from plants particularly in areas such as 'nutraceuticals' where the availability of encapsulated products has increased acceptance and use of such products. There is also increasing demand for mild, biodegradable, vegetable based materials in cosmetic and personal care markets and an increasing public awareness of issues of sustainability associated with production of crops for both industrial and food use.

Key areas to consider when introducing a new crop

To introduce a successful, long term new crop to a country there are a number of key issues that must be tackled and overcome.

Continuous research and development is required to ensure the crop will grow satisfactorily under a range of soil types and husbandry programmes. If not, at least the limits to production must be known.

Markets must be defined to assess what aspects of the crop (oil/fibre content etc) are most useful commercially, to ensure that the new crop is at least as good as or better than current raw materials sources.

End users need to be identified before embarking on significant production, to gauge reaction and information on possible material requirements. Crops should never be produced without knowing that there is demand, and preferably long term secure contracts should be in place with end users and processors before crops are released onto farm, making sure that sufficient seed supply is available.

After using initial landrace varieties, breeding programmes need to be initiated or restarted, with close liaison between all parties in the chain (Figure 2).

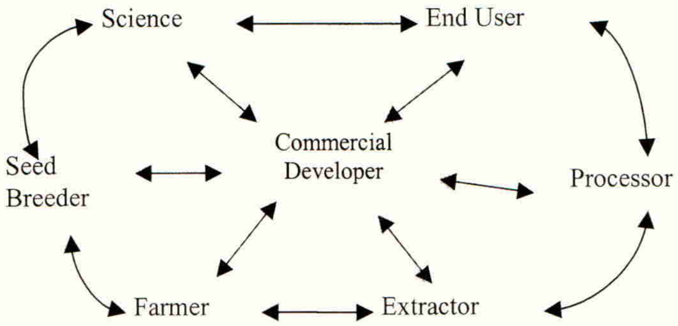


Figure 2. The non-food crop dependency chain.

Numerous trials and development work may be required to develop crop husbandry, from work on seed rates, fertiliser requirements, fungicide and insecticides to desiccants and harvesting studies.

Expansion in the use of co-products ensures improved returns and greater competitiveness against other sources of raw material.

To overcome obstacles, practical aspects of production need to be revisited and improved through persistence and enthusiasm. Growers and end users need to be kept satisfied and it is important to never under-perform.

BARRIERS TO OVERCOME

Developing end user markets

End users need a continuous supply of raw materials. No plant based products can be manufactured and delivered to requirements without sufficient lead-in time. There may also be a seasonal lead-in time, new crops need to be planned for and grown.

Manufacturers need a homogenous product. The delivered material must meet agreed specifications. In depth evaluation of causes of variation due to seasonal factors or inputs for example may be required before agreeing to any quality criteria.

Research and development is expensive and end users need to see potential returns on investment to justify investment.

The costs of changing practices can be significant. New equipment, new procedures, marketing and labelling may be required when end users switch to the use of a new product.

End users need to see a cost benefit or environmental or working practice benefit to encourage change to a new product. Industry needs to see tangible results to assess the benefits that could be obtained and all areas of the business need to agree on a benefit. There can be a conflict between technical advancement and costs involved in adoption.

Barriers to development can be overcome by providing obvious benefits to the consumer or industry such as improvements in technical efficiency, provision of a premium product, or a unique background to aid marketing, a positive environmental profile, reduced cost or improved efficiency. Development can be stimulated by supplying small quantities and building up production in a steady, controlled manner. Producers need to ensure industry satisfaction with raw materials by meeting or exceeding quality requirements. Increased interest in the industry grows on success and this stimulates both demand and competition.

Crop advancement and breeding

In the early stages of crop development there can be limited availability of germplasm (which is often derived from wild types) with poor technical specifications, poor field performance, low yield of key metabolites (oil or fibre etc) and there is restricted income to fund breeding programmes. This creates a limiting cycle that inhibits development of novel crop breeding initiatives.

This situation can be improved by developing long term markets with end users, which provides security to breeders. Ensuring that seed royalty payments get back to the breeders can also stimulate further development. In other cases, breeding programmes may need to be restarted or initiated with key aims to improve oil/fibre content and to develop and understand the basic agronomic factors affecting traits such as yield, maturity and standing power.

Crop husbandry

There is a limited range of agrochemicals available and approved for use on novel crops which can potentially create problems, particularly with weed control. In some cases specialist equipment may be required, particularly for planting or harvesting. Production of small initial quantities can also provide difficulties in handling and processing. Seed lots from early breeding programmes can be variable in terms of quality which can affect drilling operations. Care needs to be taken over land preparation. In general, development can be hampered by the limited availability of agronomic knowledge.

These problems can be overcome by agrochemical testing but those growing novel crops need greater flexibility with respect to applications and off-label uses, particularly where final products are not consumed. There is also a need for chemical manufacturers to maintain older products or to evaluate new products on a greater range of crops.

Equipment

Novel crops can provide new uses for older machines, e.g. inter row hoes etc. However, work is required to determine appropriate settings for drills with novel seeds and combine settings to optimise seed retention and cleaning. In addition, moisture meters are likely to need calibrating to deal with novel crops. Novel crops can also put pressure on the use of swathers, seed cleaners and driers at busy times.

Partnerships can be used to jointly develop crop protocols. There is often a mind set that the effort required is not worth it, however, assessment of the potential acreages that could be developed can encourage initial scoping studies.

Technical development

Agronomy is the key to novel crop development. Developed knowledge needs to be transferred throughout the on-farm advisory network by way of agronomists and supply networks. Training days and technical updates for growers and advisors help disseminate knowledge and assist with new product development. It is crucially important to counter any lack of knowledge or mis-information circulating amongst agronomists to ensure that this does not dissuade potential growers.

Improving grower uptake

There is a need to reassure growers by developing tried and tested crops. Growers are also looking for security through well defined end markets. Crop agronomy must fit with their current capabilities and they must be given access to the best available varieties. Growers are risk averse and crop prices need to be set to stimulate development. Growers respond well to the success stories of other growers.

Current problems in the grower sector include a “look see” mentality. Often growers will only try a small acreage of a new crop, which is commonly grown on the worst land to see how it fares, which does not give the crop a fair chance. Growers may also reduce on the recommended inputs in an attempt to make cost savings. Spray timings may be missed through prioritising for other mainstream crops. Harvest timings can be missed and combines may be set up poorly. In addition small seed lots may cause post harvest handling difficulties, which can jeopardise quality and the integrity of samples.

The above problems can be minimised by ensuring regular agronomic updates for growers in relation to crop timings, information on what to look out for and initiatives such as ‘pestwatches’. Regular contact with staff provides reassurance. Growers seeing the product destination is beneficial and this encourages growers to feel part of the supply chain. Field trials and open days and promotion of successful results also helps overcome grower fears and misconceptions.

Price – an essential component

Crops need to be price competitive with end users but also produce sufficient margin to garner grower interest. After time, economies of scale related to haulage, storage, crushing, extraction and processing meal and use of co-products can be exploited as volumes increase. There is commonly a 'chicken and egg' situation, where a high price is required to stimulate interest, yet economies of scale only appear once the crop is grown on a significant acreage.

Government support

Many novel and industrial crops are not supported under current IACS schemes, and until recently received no underpinning support. Growers perceived this situation as a risk with crops with which they had limited experience or where there was risk of crop loss. The extension of support for non-food crops under the recent review of Agenda 2000 provides a welcome boost for the sector.

Funding

Support funding for research is essential and it is also necessary to bring interested parties together from research, academia, industry and commercial backgrounds to link developments.

CASE STUDY

Crambe (*Crambe abyssinica*) – an example of a successful introduction.

Within the UK, Springdale Crop Synergies Ltd has been working with crambe for over 10 years and after developing the husbandry and the potential of the crop and speaking to specific end users has now commercialized the crop. After over 7 years of research the company is now in its third year of commercial production, supplying a large end user with a high quality vegetable oil rich in erucic acid. The unique fatty acid profile of the crop is shown in Table 1.

Table 1. Fatty acid composition of crambe seed oil

Fatty Acid	Content in oil (%)
Erucic	58
Oleic	16
Linoleic	8
Linolenic	5
Eicosanoic	4
Palmitic	2
Others	7

Oil content = 35%

Crambe oil has a number of uses (Table 2) and demand for the crop is growing rapidly. The potential markets allow the crop to be utilised in a number of areas, which offers security of supply and demand to growers who may be concerned about the long term potential of such crops. Careful management of the supply chain ensures that there is no overproduction and prices are maintained at sensible levels for producers.

Table 2. Major uses for erucic acid and its derivatives

	Commercial use
erucamide	polymer additive
behenyl fumarate vinyl copolymer	oil field chemical
behenyl ketone dimer	textile auxiliary
stearyl erucamide	polymer additive
behenyl trimethylammonium chloride	personal care product
brassidolide	perfumery
glyceryl trierucate	pharmaceutical
erucyl erucate	cosmetics

The main use of crambe oil is in the production of erucamide, which is used as a slip agent within the plastics industry. The fact that the resulting oil is vegetable based, fully traceable and at present non-GM is seen as a benefit by consumers.

As well as being grown for a known market, the crop confers a number of benefits to growers, a summary of which are outlined below.

Crambe is spring sown which allows growers to tidy-up problem weeds such as perennials or resistant grasses prior to sowing.

It offers opportunities for increased profitability. The crop can be grown as an industrial crop on set aside land. From 2005 it will be possible to grow the crop on both set-aside and main regime land without loss of income.

It allows farming costs to be spread over a wider acreage. Industrial cropping on set-aside allows growers to spread their fixed costs over a larger area.

Crambe is relatively drought tolerant once established and performs well on lighter soils.

There is a substantial breeding programme in progress to develop new cultivars and improve pest and disease resistance. A totally new variety will be released in 2005.

The crop shows excellent standing power. Crambe has not yet lodged in the UK.

Crambe can be harvested relatively early in the season and the likely harvest slot can be predicted and manipulated according to sowing date to optimise harvest efficiency on the farm. The crop is easy to harvest and may be swathed, desiccated or direct cut.

There are currently no GM varieties of crambe and so no issues associated with contamination.

It is an excellent break crop. Crambe has a deep tap root which may help improve the soil structure

The crop is in demand and all production is on a fixed price buy back contract.

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Development of flax and hemp agronomy for industrial fibre production

J P R E Dimmock, G R Hughes, R D Western, D Wright
School of Agricultural and Forest Sciences, University of Wales Bangor, Henfaes Research Centre, Abergwyngregyn, Llanfairfechan LL33 0LB, UK
Email: j.p.dimmock@bangor.ac.uk

ABSTRACT

The agronomy, history and politics of fibre production from flax and hemp are discussed, together with an overview of potential future market developments. Results from ongoing experiments in north Wales are presented, showing good potential for large improvements in productivity and reliability for flax, but less initial promise for hemp due to poor growth, weed problems and damage from pathogens. Gross margins available for flax and hemp production are shown to be competitive with those of major arable crops without additional price support.

INTRODUCTION

Temperate bast (i.e. stem) fibre crops, mainly flax (*Linum usitatissimum*) and hemp (*Cannabis sativa*) have historically been essential sources of raw materials for industry. Their importance has been greatly diminished over the course of the 20th century by synthetic substitutes and tropical or subtropical sources of competitor fibres, particularly cotton, but also jute, sisal, kenaf, etc. The continued supply of synthetic fibres is, however, largely dependent on supplies of petroleum, as is the long-distance transportation of materials such as jute or cotton. Political and public interest in increasing sustainability, together with the development of new products and markets has renewed interest in these potentially highly productive and versatile crops (Smeder & Liljedahl, 1996). This paper seeks firstly to describe the crops, then outline the political and commercial environment in which they are grown and finally to report some of the advances towards exploiting their potential that have recently been made at Bangor.

Flax

Flax has been cultivated since prehistoric times for the production of its fibres, which are fine and soft to the touch whilst also strong and highly durable; characteristics ideally suited to high quality textile production. Flax is an annual with a thin, erect and wiry stem that can be grown for both fibre and seed. Fibre cultivars may grow to about 1.2 m, and through sowing at high rates, typically between 800–2000 seeds/m^2, field-grown crops show little branching except at the top of the stems where a number of flowers form. Cellulose fibres develop around each group of vascular bundles in the stem cortex, bound together with pectin. The growing period is short. Seeds are drilled from late March to early May, and after rapid development the crop is desiccated in July shortly after the onset of flowering and harvested after a period of retting (Langer & Hill, 1991). Retting is a process that allows microorganisms to decompose pectins in the vascular bundles, easing release and removal of cellulose fibres from the woody core of the plant (shive) during the process of decortication or scutching (Easson & Molloy, 1996). Traditionally bundles of flax were retted in rivers or in open pools, but this practice is no longer accepted in Europe due to environmental pollution and it has been replaced by in-field dew-retting, where rain and dew usually produce the intended effect.

Hemp

Hemp also has a long history of production, with cultivation recorded some 4500 years ago in China (Langer & Hill, 1991). The plant is annual and herbaceous, and grows up to 4 m in height. Again, the degree of branching of individual stems is reduced by using high sowing rates, typically 100–300 plants/m^2 for fibre production. Fibres are produced in the stem in much the same way as flax. Hemp is sown from late April to mid-May as development is slow below 10°C. Following establishment the crop grows rapidly, typically reaching 2–3 m by mid-August. Harvesting usually involves swathing the crop and dew-retting in the swath. This takes from 3 to 5 weeks and necessitates frequent turning to ensure even retting. Hemp fibres are coarser than those of flax as a result of greater lignification, so the crop is more suited to rope and heavy-duty textile production.

Political and commercial pressures on fibre production

Use of both hemp and flax declined in western Europe for a variety of reasons. These include pollution resulting from water-retting techniques causing a change to the less reliable and lower quality alternative of dew-retting; increased production costs from traditional fibre scutching and hackling methods and availability of cheaper alternative products such as synthetic fibres and cotton. However, with increasing emphasis now being placed on the sustainability and carbon-neutrality of industrial feedstocks, there has been renewed interest in these crops. For a number of reasons, alternative materials are now being sought to replace those derived from petroleum, i.e. most synthetic fibres, or crops such as cotton that require high inputs of pesticides. A wide range of end uses have been identified that offer clear benefits both to the environment and to customers from using flax and hemp fibres. Examples include insulation products to replace mineral wools, providing reduced respiratory and handling hazards and also lower decommissioning costs through composting rather than landfill. Another high profile use for flax and hemp fibres is in moulded biocomposite panels for the automotive industry, which give numerous advantages over synthetic products in terms of weight reduction, better acoustic performance, non-toxic fumes on combustion, ease of disposal at end-of-life and reduced risks to workers during production.

Unfortunately market confidence in industrial fibres has been damaged by the dramatic changes in subsidies available under the Common Agricultural Policy (CAP). During the 1990s, high aid levels (typically around £570/ha) enabled the development of a model for fibre production based on simple agronomic practices and minimal specialist machinery on farms, feeding low-cost straw into high throughput factories producing short fibres for the emerging markets described above. Rapid expansion of production occurred, leading to the establishment of crop processing plants throughout Europe. These developments, however, took place in a market where average flax yields were only 1.5–3.0 t/ha and worth £20/t (Nix, 1997). Straw sales therefore represented only 5% of the value of the subsidy for growing the crop, meaning that no motivation existed for developing agronomy or commercialising natural fibre products, as the crop could be grown profitably for the subsidy alone. Following CAP reforms in 2001 where fibre crop aid was cut to the same rate as for cereal production, this lack of commercialisation resulted in a rapid decline in the industry, to the extent that of the seven processing plants operational in the UK in 2000, only one is now trading at a significant level.

In order to provide for an industry that is market rather than subsidy-driven, weaknesses in fibre crop production and productivity must be fully addressed. The first of these issues is low productivity, particularly that of flax. Without price support, yields of around 2 t/ha mean flax straw has to be worth around three times the value of barley grain to make planting worthwhile for farmers. The second issue is whether a crop of sufficient quality can reliably be produced for technical market outlets, as the degree and evenness of retting is crucial to the further processing of the straw. The importance of this is seen through crop rejection rates during the 1990s, which were typically around 40% (BioFibre Europe Ltd., personal communication). A genuine market cannot sustain failures of this magnitude, as growers will be unwilling to take risks without a large price premium. Irregular supply of fibre will also fail manufacturers who need consistent supplies of quality raw materials.

Research at Bangor

Our work seeks to enable a consistent supply of fibre of sufficient quantity and quality to facilitate market development whilst advancing crop productivity to a point where it presents a worthwhile commercial proposition for farmers. We began from a low knowledge base, as relatively little material is available in the scientific press about flax and particularly hemp production, and of the existing research material, much is concerned with long fibre production for linen. In addition, whilst 29 cultivars of flax and 26 of hemp are eligible for financial support under the EU Arable Area Payment Scheme in 2003, there is no guidance available as to the comparative characteristics of these cultivars.

Research began in 2001 with a series of pilot plot-scale experiments at Henfaes, alongside commercial scale grower-participative research in which farmers cultivated substantial quantities of flax and hemp crops applying variations on previously used short fibre cultivation practices such as different sowing rates (40 or 80 kg/ha), drilling times between April and early June and the use of different chemical desiccants. From this work it was determined that for 2002, plot-scale replicated field experimentation investigating the performance of a wide range of genetic material was necessary, so flax and hemp cultivars from throughout Europe were obtained. In addition, on the basis of experiences during the pilot trials and on work by Easson & Cooper (2002), stand-retting was adopted for all experiments. This method produces a slower, more controlled ret than where the crop is swathed, and is likely to reduce crop failures in the wet climate of west Wales, where excessive decay in wet straw can markedly reduce fibre yields. In addition to producing a slower and more homogeneous ret, this technique can reduce losses through enabling baling after a shorter drying period than is necessary for a swathed crop. Stand-retting offers further advantages, as dew-retted straw swath needs frequent turning and can be difficult to mechanically bale, leading to yield losses. Additionally, dew-retted straw is often contaminated with stones and soil, increasing the likelihood of crop rejection and damage to processing equipment.

Straw and fibre yields from both flax and hemp in our 2002 experiments are presented below together with a breakdown of the current value of fibre crop outputs. Potential gross margins are also compared with those available from cereal production.

METHODS AND MATERIALS

Flax was drilled on 9 April 2002 in 10 m × 1.8 m plots with 12 cm between rows following conventional ploughing and cultivation, using randomised blocks with four replicates. Seeds were drilled to 15 mm at a rate of $1000/m^2$. Fertiliser was applied to the seedbed before final cultivation at the rate of 40 kg each of N, P & K as NH_4NO_3, P_2O_5 and K_2O respectively. Bentazone (Basagran; BASF UK Ltd.) herbicide was applied at 1.44 kg a.i./ha in mid-May, and the crop was desiccated with glyphosate trimesium (Touchdown; Syngenta) at 4 litres/ha on 29 July at 35 days past mean mid-flowering point (MPF). This is the time defined by Easson & Cooper (2002) as the point where 50% of buds present have opened. Plots were harvested with a pedestrian-operated finger bar mower during October 2002. Sub-samples were oven-dried for dry matter determination and to allow yields to be corrected to 16% moisture content. A further sub-sample was also rippled (i.e. seed capsules were removed by combing) to assess the proportions of straw and seed to calculate overall straw yields. Fibre contents were then determined in accordance with Long *et al.* (1988).

Hemp was drilled on 24 April 2002 using the same equipment and experimental design, using seed rates of 150 and 300 $seeds/m^2$. A fertiliser application of 80 kg N, 80 kg P & 160 kg K as NH_4NO_3, P_2O_5 and K_2O respectively was made to the seedbed immediately after drilling, followed by a further application of 80 kg N when five pairs of leaves were visible. The crop was desiccated with glyphosate trimesium, applied at 4 litres/ha on 15 August 2002 and harvested by hand in the week beginning 16 September 2002. Straw was weighed and sub-samples taken for drying to correct for dry matter content.

RESULTS AND DISCUSSION

Flax straw and fibre yields from replicated field experiments are shown in Table 1 together with mean yields attained by growers in 2001 for comparative purposes. Table 2 shows hemp straw yields obtained from field experiments.

Flax yields from the cultivar trials were substantially in excess of those returned by growers in 2001. The best-yielding group of cultivars produced over 7 t/ha of straw, reflecting a potential for improvement in commercial production systems of 300%. Laura, the cultivar used by commercial growers in 2001, possibly performed better in our experiments due to earlier sowing, as many commercial crops in 2001 were not drilled before early May. Following fibre determination, even greater increases in performance were seen over 2001, with the leading cultivars yielding a five-fold increase in fibre production over that of the commercial growers in 2001. It is also significant that Alice, a dual-purpose cultivar intended to produce worthwhile quantities of both fibre and seed performed poorly both in terms of straw yield and in fibre percentage, reflecting the difficulties reported by Foster *et al.* (1997) in breeding such a desirable cultivar. The applicability of stand-retting techniques to this high-yielding group of flax cultivars is currently being investigated with promising results in terms of standing ability and ease of decortication. The commercial use of glyphosate-mediated stand-retting has already paid dividends, having reduced crop rejections due to over-retting from 45% in 2001 to zero in 2002.

Table 1. Straw and fibre yields of flax cultivars in 2002 experiments compared with mean straw yield from growers in 2001 (primarily cv. Laura); SED is provided for between-cultivar comparisons in 2002.

Cultivar	Straw yield (t/ha; 16% mc)	Fibre %	Fibre yield (t/ha; 16% mc)
2001 mean	*2.65*	*17.0*	*0.45*
Alice	5.55	17.8	0.96
Aurore	7.36	33.0	2.45
Diane	7.52	28.9	2.14
Electra	7.93	32.3	2.70
Elise	6.82	28.1	1.65
Laura	5.48	22.2	1.20
Liviola	7.35	28.8	2.04
SED	0.60 (160 d.f.)	3.5 (154 d.f.)	0.30 (152 d.f.)

Table 2. Mean straw and fibre yields of hemp cultivars in 2002 field experiments.

Cultivar	Straw yield (t/ha ; 16% mc)	Fibre %	Fibre yield (t/ha ; 16% mc)
Beniko	5.94	36.7	2.19
Bialobrzeski	5.91	40.4	2.53
Fasamo	1.43	29.4	0.52
Fedora 17	6.71	31.2	2.06
Felina 34	6.57	24.9	1.61
Ferimon 12	5.44	21.0	1.13
Futura 75	7.17	35.3	2.44
USO 31	2.42	32.6	1.13
SED	0.55 (24 d.f.)	5.5 (23 d.f.)	0.42 (24 d.f.)

Hemp yields were lower than expected, with the best being just under 7 t/ha, in contrast to the 10 t/ha reported by Cromack (1998) in southern England. Performance of cvs. Fasamo and USO 31 was particularly poor, probably because of excessive weed competition reducing growth in early stages, and due to the fact that both are early-maturing cultivars. This has impacts on both fibre yield and quality, as metabolism of the mature hemp plant favours seed production over fibre production, and existing fibre becomes increasingly lignified and therefore of lower quality. Weed problems also limited growth in the other cultivars, but their longer vegetative phase allowed greater straw yields to be obtained. There are currently no herbicides available to control weeds in hemp. Despite the successful use of stand-retting in our plot-scale experiments, dew-retting with its associated high risk of crop rejection is still commonly used in commercial hemp-growing. This is because the height of the crop, often exceeding 2.5 m, prevents the use of conventional sprayers. Substantial levels of *Botrytis* infection within the crops also caused fibre losses through reduction in stem strength, resulting in breakage. Whilst fungicides may control this problem, the expense and difficulty of application may prevent commercial usage.

Having shown that substantial yield improvements can be obtained over previously reported levels, the question remains as to whether flax and hemp can compete against major arable crops without additional support. A measure of the viability of commercial fibre crop production can be gained through comparing gross margins (GM) expected from standard arable cropping with average productivity and costs (Nix, 2002) with yields and variable costs derived from our own experiments (Table 3). It is shown that GM parity with major crops is currently obtainable at a straw price of £60–70/t. Since Hemcore are currently offering in excess of £100/t for hemp straw, it appears that attractive gross margins are already available to growers. Evidence that such returns are sustainable and also applicable to flax is provided in Table 4, where proportions and value of the straw components (i.e. fibre, shive and dust) are given together with a calculation of processing costs as provided by BioFibre Europe Ltd. (personal communication). It is shown that the value of the shive (as horse-bedding) effectively covers the cost of processing, enabling the value of the fibre to provide a competitive return to both grower and processor. Furthermore, as demand for novel products from industrial fibre that are currently in development grows, returns are likely to become even more competitive.

Having demonstrated that fibre crops have the clear potential to provide worthwhile returns to growers without further subsidy, their broad range of potential environmental benefits will only be realised if adequate provision of processing facilities is made available, and as such, the success of these crops is dependent on substantial investment either from the public or private sectors in this essential role.

Table 3. Average gross margins (GM) from arable crops (Nix 2002) with fibre crop straw prices given in italics required to match the GM currently available from winter barley. Variable costs for flax and hemp include £50/ha for straw haulage.

Crop	Yield (t/ha)	Value (£/t)	Area Payment (£/ha)	Variable costs (£/ha)	GM (£/ha)
Winter wheat	8.0	62.50	225	225	500
Winter barley	6.4	60.00	225	185	425
Winter oilseed rape	3.2	135.00	225	210	445
Hemp	7.0	*68.60*	225	280	425
Flax	7.0	*57.14*	225	200	425

Table 4. Proportions of flax and hemp straw components, market value and processing costs

Component	Fibre	Shive	Dust	Processing cost	Total value
Market value (£/t)	400	160	0	77	-
Proportion of straw (%)	30	50	20	-	-
Product value (£/t)	120	80	0	77	123

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Liquid biofuels – an opportunity for UK agriculture ?

D B Turley
Agricultural and Rural Strategy Group, Central Science Laboratory, Sand Hutton, York, Y041 1LZ, UK
Email: d.turley@csl.gov.uk

ABSTRACT

The UK has taken a leading position in seeking means to reduce greenhouse gas emissions. Liquid biofuels derived from agricultural crops, crop residues and novel biomass crops offer a means of reducing greenhouse gas emissions from the transport sector, a key contributor to UK CO_2 emissions. However, incentives to date have failed to stimulate significant production in the UK. Indicative targets for substitution of fossil fuels have been proposed by the EU. Meeting these targets is likely to have significant impacts on UK cropping patterns and UK agriculture. Is it likely that significant benefits will flow to the agricultural sector as a result of liquid biofuel cropping and are liquid biofuels the most cost effective means of mitigating CO_2 emissions ? These and other issues are discussed in the paper.

INTRODUCTION

The UN Framework Convention on Climate Change (UNCCC) commits signatories to the Kyoto Protocol to tackle the effects of climate change at an international level by taking steps to significantly reduce greenhouse gas emissions. Real progress towards a 5% global reduction (against a 1990 baseline) is expected by 2008-2012. The UK is committed to reducing greenhouse gas emissions by 12.5% in this period. The UK Government recently outlined its aim of creating a low carbon economy, which includes investment in 'clean' low carbon transport (DTI, 2003). Transport accounts for around 25% of UK greenhouse gas emissions, the majority (85%) derived from road transport. Biofuels derived from agricultural materials have significantly lower carbon lifecycle emissions than fossil derived fuels and could play a significant role in helping the UK to meet its targets. The EU has proposed indicative targets for biofuel substitution of 2% by 2005, rising by 0.75% per annum to 5.75% by 2010. In response, the UK will shortly have to confirm and ratify its own targets.

Biofuel feedstocks

In international markets, biodiesel, derived commercially from trans-esterification of plant oils and animal wastes (typically oilseed rape and sunflower as well as waste vegetable oils, animal fats, grease and tallow) and bioethanol (derived from fermentation of starch or sugar crops) dominate as the most technically feasible and commercialised biofuel sources. Most car and truck manufacturer warranties currently allow inclusion of appropriate biofuels in blends of up to at least 5% with fossil diesel or petrol. Production of bioethanol by fermentation of starch and sugar feedstocks has been undertaken for many years in Brazil (from sugar cane) and the US (from corn), and more recently in the EU from wheat and sugar beet (France, Spain and Sweden). These represent relatively expensive feedstocks and research is ongoing to commercialise the production of bioethanol from lignocellulosic sources, i.e. paper and plant wastes (such as straw residues) and wood. More complex physiochemical or enzymic processing is required to release the sugars for fermentation. This technology is some 5-10 years away from commercialisation, but offers the potential to diversify feedstocks and reduce costs of production. The potential biofuel yields obtainable from UK produced feedstocks are shown in Table 1.

Table 1. Biofuel production potential of UK agricultural feedstocks. ([a] Derived from Marrow, Coombs and Lees 1987, [b] derived from Marrow and Coombs, 1990. [c] Derived from industry estimates (Cargill and North East Biodiesel)).

Biofuel feedstock (typical field yield)	Feedstock requirement (tonnes) per tonne of biofuel produced	Potential biofuel yield (tonnes/ha/yr)
Bioethanol		
Wheat (8 t/ha)	2.5-3.0 [a]	2.6 – 3.2
Sugar beet (53 t/ha)	11-12.5 [a]	4.24- 4.82
Coppice/forestry waste	5.5-7.5[b]	1.2-1.65
Straw residues	4.25-6.25 [b]	0.75-1.05
Biodiesel		
Oilseed rape (3.5 t/ha)	2.4 [c]	1.45

Targets for substitution and current levels of production

UK fuel demand is predicted to reach 40.3 M tonnes by 2005 and 44.5 M tonnes by 2010. Based on the EC indicative targets, this gives a target for substitution of 0.8 million tonnes in 2005, rising to 2.56 million tonnes in 2010.

The cost of production of crop-derived biofuels is 2-3 times that of mineral fuels. Figures from Cargill (who produce biodiesel in Germany) indicate that over the past 3 years biodiesel cost between 22 and 33 p/litre more to produce than fossil diesel (which cost between 12 - 14p/litre over the same period). This differential is reduced at the point of sale by reductions in, or (as in some other EU member states) by exemption from fuel duty payments. Current UK fuel duty rates provide for a 20p/l reduction for biodiesel over conventional Ultra-Low Sulphur Diesel (ULSD). A similar duty cut for bioethanol will come into force from January 2005. This duty rebate has incentivised commercial UK production of biodiesel from waste oil, but little production from fresh rapeseed oil. Current production is running at just under 800 tonnes per month (May 2003) around one quarter of which is sold as a blended diesel product. There is currently no bioethanol production in the UK.

A problem for feedstock producers is that, raw material costs (ex duty) account for between 62% (North East Biodiesel) and 78% (Cargill) of biodiesel costs and 60-70% (Ballesteros, 2002) of bioethanol production costs (from wheat). This results in pressure to keep feedstock costs as low as possible, as variation in such costs has a significant effect on the point of sale price (Figure 1). In the 1992/93 season, oilseed rape prices ranged from a low of £135 up to £180/tonne which had a significant impact on competitiveness of any UK produced biodiesel with fossil diesel trading around 0.78p/litre. Since biodiesel and bioethanol can be made from a wide range of feedstocks the cost of competitor oils (e.g. soya), starch and sugar (e.g. corn starch and cane sugar) sources also keeps prices competitive. Increasing support to the industry through further cuts in rates of duty would risk increasing import of biofuels from other countries with more liberal support measures and lower costs of production, though, with the exception of Brazilian ethanol, domestic demands mean there is currently little international trade in biofuels.

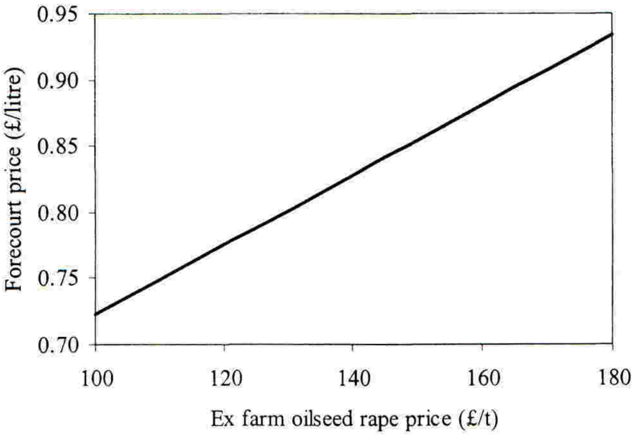

Figure 1. Effect of oilseed rape cost on final cost of biodiesel at the pump, based on current conversion efficiencies and at prevailing rates of biodiesel fuel duty (25.82 pence/litre).

Meeting the EU biofuel substitution targets

In the short term it is likely that only production of biodiesel will be sufficiently well developed commercially in the UK to contribute significantly to meeting the biofuel substitution targets for 2005. Biodiesel production from waste oils and fats will only meet a fraction of demand, limited to around 0.1 million tonnes (Ecotec, 2002). A further 0.2 million hectares of oilseed rape would be required to meet targets for substitution of road diesel alone and just under 0.5 million hectares to substitute for 2% of all transport fuel requirement in 2005. This would represent a significant increase in the oilseed rape area of between 45 and 108% (assuming the existing area is retained for current market outlets). Meeting the target for 5.75% substitution will require a much broader range of biofuel feedstocks.

For a number of reasons, including rotational limits on production of OSR in traditional growing areas, it is unlikely that biodiesel derived from UK oilseed crops will be able to significantly exceed 2% of UK transport fuel demand. Other feedstocks will be required to meet the demand. The UK produces a significant exportable cereal surplus of around 2.9 million tonnes, but it is unlikely that all of this would be available for bioethanol production. In addition, forthcoming reform of the EU sugar regime and opening up of the sugar market to imports from developing countries is likely to significantly affect profitability of UK sugar beet production and the industry is predicted to contract over the next 10 years. For illustrative purposes it is assumed that around half of the exportable wheat surplus could be made available for bioethanol production and that at least half of the current area of sugar beet is retained and used for bioethanol production in 2010. Even with this level of supply directed towards biofuels, there would still be a requirement for a further 1 million tonnes of bioethanol production to meet the 2010 substitution target. This demand would have to be met from novel sources such as lignocellulosics. A possible breakdown for supply from these sources is given in Table 2, which indicates that up to 1.2 million hectares of land in the UK would need to be directed towards biofuel production to meet the indicative targets for 2010.

Table 2. Possible scenario for biofuel feedstock cropping to meet the 2010 target for biofuel substitution.

Feedstock	Fuel required (million tonnes)	Feedstock area (thousand ha)	% of current crop area
Waste fats/oils	0.10		
Rape oil (RME)	0.70	459	102
Wheat grain	0.40	173	11
Sugar beet	0.40	98	55
Wheat straw	0.25	164	10
Miscanthus	0.20	100	-
Short rotation coppice	0.50	229	-
Total:		1,222	

An outcome of the recent mid-term review of the common agricultural policy (CAP) was that it will still be possible to grow crops for industrial use on set-aside. In the last three years between 560-800 thousand hectares have been set-aside and a significant proportion of this area could be devoted to biofuel cropping, which would ease competition with crops for food markets. It is by utilising this 'additional' land resource that the greatest financial and employment benefits will flow back to the agricultural sector. The alternative approach is that crops would just be diverted from food to industrial use, or would substitute for other crops in the rotation with little net benefit to producers. To meet the proposed biofuel targets there would need to be a mix of approaches. There would be consequences for the environment associated with any increase in winter over spring cropping and reduction in the area of naturally regenerated set-aside, favoured by some key farmland bird species. Pesticide and fertiliser use would increase where set-aside is used for biofuel cropping. However, development of lignocellulosic technologies would help stem such increases by increasing the efficiency of biofuel production per unit area of arable feedstock crop by utilising 'waste' biomass (e.g. straw). Similarly, short rotation coppice and miscanthus biomass crops have a relatively low demand for agrochemical and fertiliser inputs. In general, except for the noted possible effects on set-aside, production of biofuels from a broad mix of arable crops should have a neutral effect on the farmed environment. Environmental mitigation measures may be required where biofuel feedstock crops are produced on set-aside land. These could include features such a grass field margins.

Impacts on the rural and wider economy

As part of the mid term review of CAP, it has been agreed that an Energy Crop Payment of €45/ha/year (currently worth £32) would be made available to support biofuel energy crops up up to a maximum guaranteed area (MGA) of 1.5 million hectares across the EU, with a proportionate scale back where this is exceeded. The scale of production required to meet the biofuel targets combined with better incentives in other EU countries, as well as competition with solid biofuels for electricity generation, means that the MGA will be rapidly overshot. Assuming UK oilseed rape producers could access the full payment rate, at current yield levels this would provide some compensation (i.e. £9/tonne for a 3.5 t/ha rape crop) where low prices are being offered on contracts for biodiesel production. Prices being discussed within the biodiesel industry are currently around of £8-12/tonne less than those currently available for conventional oilseed rape market outlets. Those wishing to procure feedstocks hope that the offer of long-term supply contracts will encourage production of biofuel crops. The best returns to growers are likely to arise from expansion of cereal and oilseed biofuel cropping onto set-aside which could improve returns to growers by up to £120-£300/ha.

A UK biofuel industry will create employment opportunities but these are likely to be limited. Turley, *et al.* (2002), calculated that around 2 jobs were created in the rural economy and associated industries per 1000 tonnes of biodiesel production where rape feedstocks were grown on set-aside, this would be negligible where biofuel crops replaced crops grown for feed markets. Recent work by Bullard, *et al.* (2003) estimated that bioethanol production from wheat and sugar beet could create 5.5 jobs/1000 tonnes of production. Very few additional jobs are created in processing. A 100,000 tonne biodiesel plant would employ in the region of 62 staff and a similar sized bioethanol plant around 75 jobs in production, blending and transport (Bullard, *et al.*, 2003). Impacts on the wider economy are difficult to calculate but Bullard, *et al.* (2003) estimate that UK bioethanol production could return around 6.5 pence to the Exchequer for every litre sold, though savings in job seeker allowance (created by increased employment) and taxation revenues arising from growth in ancillary industries.

Carbon savings

There has been considerable debate over the carbon savings derived from biofuels. Latest figures indicate greenhouse gas savings of between 51 and 65% for bioethanol (v Ultra Low Sulphur Petrol), 56-80% for Rape Methyl Ester and 84% for biodiesel derived from waste oil (v ULSD) (Mortimer, *et al.*, 2002, Woods and Bauden, 2003). Meeting the biofuel substitution targets would result in carbon savings of around 0.5 M tonnes by 2005 rising to 1.5 to 2 million tonnes by 2010, costing the Exchequer £197 million in 2005, rising to £630 million by 2010. The cost of greenhouse gas abatement achieved by biofuels (CO_2 saving per £ subsidy expended) gives CO_2 abatement costs ranging from £91-£143/tonne for bioethanol derived from wheat and £110-£178/tonne for biodiesel derived from rapeseed (£76/tonne from waste oil). The equivalent cost of CO_2 savings generated by electricity generation from short rotation coppice is around £51/tonne (Mortimer *et al.*, 2003). When lignocellulosic technologies are commercially developed, the cost of CO_2 abatement for biofuels is likely to improve as the CO_2 savings associated with these feedstocks are likely to be greater.

CONCLUSIONS

Biofuel cropping offers an opportunity to diversify market outlets for UK growers and to derive added value from crop production on set-aside land. However, at current levels of industrial efficiency and cost, returns to growers for feedstocks grown outside set-aside are likely to be similar to, or less than, those of traditional market outlets, though with some security derived from the offer of long term contracts. Extensive biofuel cropping is likely to result in loss of natural regeneration set-aside and could result in intensification of some crops, in particular oilseed rape for biodiesel production. This could result in agronomic difficulties in achieving timely crop establishment where rape starts to occur more than once in the rotation, but these difficulties are not insurmountable.

The costs of carbon savings achieved by adoption of current biofuel technologies and supported by fuel duty cuts, appear uncompetitive compared with other possible CO_2 mitigation measures (i.e. renewable energy generation and investment in energy saving technologies) and this may hamper provision of additional Government support. However this could prevent development of technologies and initiatives that could quickly deliver real benefits in terms of reduction in greenhouse gas emissions on a wide scale. Other lower-cost incentives which could be adopted to stimulate the industry, without increasing the risk of imports, includes introduction of mandatory targets for biofuel blends, which would pass costs to consumers, or support with grants to cover capital costs, which would reduce costs to the Exchequer in the long term. Technologies could be developed to produce bioethanol much more cheaply from lignocellulosic raw materials while providing greater reductions in CO_2 than are possible with current technologies, but this step will not occur in the UK without investment and development in current technologies as a stepping stone. Given the political will to support the industry, in the medium to long term, novel biomass feedstocks are likely to be the key industrial crops required for UK liquid biofuel production.

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