Agricultural Engineering:
a key discipline for agriculture to deliver global food security

A status report developed by IAgrE in response to the UK Government's Foresight Project: Global Food and Farming Futures

IAgrE

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IAgrE is the professional institution of choice for scientists, engineers, environmentalists, technologists, managers, lecturers and students in the landbased sector.

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Managing Extreme Rainfall Events

Practical solutions

The Challenge

On susceptible soils, slope, row-orientation and agronomic practices can combine to concentrate runoff and facilitate gully formation. On such terrain, during extreme rainfall, unless practical remediation actions are taken, the risk of soil erosion with associated on-field and off-site impacts is extremely high.

The Solution

Here a geotextile lined grassed water way has been designed and installed to control runoff and erosion from an asparagus field. This is in combination with on-field measures aimed at promoting infiltration and thus minimising the risk of runoff generation. The resultant combination of on-field water management and engineering options reduces both water runoff and associated soil losses to acceptable levels.

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Foreword

The Foresight Report 'The Future of Food and Farming: Challenges and Choices for Global Sustainability' concluded that "the global food system faces formidable challenges today that will increase markedly over the next 40 years. … Much can be achieved immediately with current technologies and knowledge, given sufficient will and investment. But coping with future challenges will require more radical changes to the food system and investment in research to provide new solutions to novel problems."

Engineering has a major contribution to make to the required advances in sustainable farming and food, in sympathy with the environment. The UK response to global food security will be much stronger if agricultural engineering is recognised as a critical component, capable of breaking down traditional barriers and enhancing multidisciplinary approaches to challenges. A new approach to encouraging appropriate developments in the sector is required, ranging from stronger links with the UK engineering research base, building effective centres of excellence that can translate science into practice, and an engagement of government and industry to ensure that education and training provide the skilled work force and future innovators that UK's contribution to global food security will demand.

Agricultural engineering is a recognised focus of engineering skills and innovation that takes a strongly multidisciplinary approach to agricultural problems. The IAgrE is the professional institution that represents agricultural engineering, in business, education and research organisations, and offers this report as a contribution to the debate, seeking to highlight the role that agricultural engineering can take and the opportunities that engineering, allied with other disciplines, is already offering as part of a vision for future global food security.

The American Society of Mechanical Engineers identified agricultural mechanisation as one of the top ten achievements in mechanical engineering in the 20th century. Agriculture was a gruelling and laborious business, but mechanisation reduced the drudgery, increased outputs and allowed operations to be carried out at the right time. The advances in the last 100 years in drainage and irrigation, in tractors, tillage and crop protection, and in harvesters and cool chain management all derive from agricultural engineering innovation. Now we have a new revolution in information and control technologies, and in engineering science to understand the performance of highly complex systems and provide routes to optimised operations from farm to fork. These advances can provide similar benefits in the 21st century, not just to the farmer but also to the environment, the food chain and the global consumer.

Peter Leech and Andy Newbold
IAgrE Presidents, 2010-2012 and 2012-2014

The Foresight Report 'The Future of Food and Farming: Challenges and Choices for Global Sustainability', which I launched last year, highlights major challenges to global food security. Deploying new and existing technologies, processes and knowledge that help make farming methods and practices more sustainable, while having less impact on the environment, will be important. I welcome this report in highlighting the importance of agricultural and biosystems engineering in contributing to these advances.

Professor Sir John Beddington CMG, FRS
Chief Scientific Adviser to HM Government, and Head of the Government Office for Science

Advances in agricultural engineering have delivered some of the most significant developments we've seen in modern farming. These aren't technologies of tomorrow, they are already being used by many farming businesses today, for example technical developments in nozzle design to improve sprayer efficiency and minimise the risk of drift, or the robotic milking of dairy cows. However, we've only seen the tip of the iceberg in terms of what this area of R&D can deliver for our industry in the future. This is why the NFU believes that the recommendations set out in this report are crucial to raise the importance of this area of agricultural innovation to help us meet the challenges of sustainable intensification.

Peter Kendall
President - NFU

The future sustainable intensification of crop and livestock production systems will require a high level, precision farming approach for its delivery, and agricultural engineering R&D will be pivotal to this achievement.

Professor David Leaver
President of BIAC (British Institute of Agricultural Consultants)

Executive Summary

This report has been stimulated by discussions with the Government Chief Scientific Adviser and others following the publication of the Foresight Report "The Future of Food and Farming: Challenges and Choices for Global Sustainability", which highlights major challenges to global food security.

Many systems of food production are unsustainable. Without change, the many current approaches will continue to degrade the environment and compromise the world's capacity to produce food in the future, as well as contributing to climate change and the destruction of biodiversity. The vision for the future of agriculture identifies sustainable intensification, and a systematic approach to deal with agricultural change in a "climate-smart" way as key. Such approaches need to include technological advances based on engineering science, and the use of systems models to provide an integrated understanding of the benefits and risks associated with new practices. There is scope for a wide range of physical science and engineering disciplines to play a part. *The contribution of engineering needs to be more widely recognised in meeting societal challenges in global food security and contributing to economic growth* (**Recommendation 1**) and an engineering community addressing these issues needs to be established with effective links to the key stakeholders.

This report illustrates the potential contribution that agricultural and biosystems engineering can provide to advances in productivity, profitability and environmental sustainability. Agricultural engineering is essential to delivering value from innovation in other disciplines, and engineers work effectively in multidisciplinary teams to solve problems and deliver innovative solutions.

Case studies included in this report provide examples of this contribution, demonstrating inter alia that:

- Sophisticated sensing technologies like real-time computer-based image analysis can be used with confidence to control agricultural machines, and permit for example effective weed management with minimal pesticide
- Robotic systems and sensors open new doors to working with animals, to address productivity and welfare issues
- Pesticide efficacy and safety are being improved through new technologies and systems based on an understanding of fluid flow and dispersal in the natural environment, and there is a strong UK industry translating these advances into products for UK and for export
- Soil damage from traffic can be substantial but can be reduced by understanding and managing tyre-soil interactions, including the adoption of controlled traffic farming
- Soil quality is a critical factor globally, and translating understanding of how to manage soil into viable practical systems will benefit food supply and the environment. Conservation Agriculture offers a platform for advances in developing countries, but its adoption requires a new look at mechanisation, especially the ways to integrate approaches with indigenous manufacturing capability and infrastructure.

The benefits to UK interests and the economy will be considerable. New engineering science and its translation to deliver results in the complex and challenging environment of agricultural systems will complement advances in biology.

Delivering the contribution that agricultural engineering must make for scientific advances to reach practice is a significant challenge that needs effective strategic engagement by the key stakeholders. The challenge is *to develop the important opportunities for education, research and training in engineering for agriculture* (**Recommendation 2**) in ways that engage the agricultural engineering community itself with other engineers, biological scientists and agriculturalists.

The agricultural engineering business sector in the UK is substantial, with a significant focus on production of higher value machines such as loaders and sprayers. Consolidations among global manufacturers of high volume machines (tractors etc.) have reduced the large scale R&D facilities in the UK, and JCB is now the only fully integrated and globally-leading player in specialised agricultural as well as construction machinery. However the sector is still dynamic and innovative, with many SMEs capable of grasping opportunities to take advanced technologies into practice.

Skills and capability are required in the science base, the education system and in industry. Centres for education, training and innovation have declined and need to be revitalised to provide expertise at the interface between engineering and biological systems. Education to first degree level specifically in agricultural engineering is now delivered by just one University College (Harper Adams) and with rising demand, output is near capacity. Mechanisms to enhance provision and ensure sustainable resourcing are needed. IAgrE is already stimulating and supporting bodies seeking to provide appropriate education and training, and will develop and sustain this activity. The reputation of the UK for agricultural engineering training and education is still high around the world, despite the recent decline in provision. Training overseas students has established major relationships with many developing countries, and there is a real opportunity to rebuild this bridge, to the benefit of the UK's global development agenda.

The role of agricultural engineering in responding to the challenges identified by the Foresight Global Food and Farming Futures Project

'Balancing future demand and supply sustainably' - precision management of inputs, detection of disease and control of production systems, and more efficient use of key resources such as irrigation water to deliver sustainable intensification.

'Addressing the threat of future volatility in the food system' - farm systems models and operational research to understand more clearly how interventions are likely to affect farming practice and outputs, and investment of skills and management advances into storage regimes and facilities to buffer food supply chains against local or regional disruption.

'Ending hunger' - translation of agricultural engineering approaches in sympathy with local conditions as a strong basis for development, strengthening local infrastructure and supply chains, facilitating appropriate mechanisation and postharvest systems that can link poor and smallholder farmers to the market.

'Meeting the challenges of a low emissions world' - understanding and tools to improve efficiency of resource use, optimising the management of crops and animals so emissions can be minimised per unit of food delivered, and reducing the energy demands of vehicles and processes.

'Maintaining biodiversity and ecosystem services while feeding the world' - coupling understanding of the biological system and natural environment with the approach to production management: e.g. better methods of targeting pesticides to preserve ecosystems and biodiversity as production intensifies; and soil management machines and methods to sustain production, maintain soil quality, and minimise pollution and flooding risk.

Improving agricultural efficiencies

Yield Mapping

The Challenge

Fields are not homogenous yet traditionally, agro chemicals have been applied in a blanket fashion yet ideally, should be applied only where needed.

The Solution

By precisely measuring and recording the flow of grain through a combine harvester at the same time as recording the machine's movement through the field, it is possible to produce yield "contour maps". Data from these maps can then be used to determine what

in-field treatments are needed with appropriate reduction in agro-chemical usage.

IAgrE, working with industry, has established an accreditation scheme for technician training that is having a major impact on the professional standing of technicians for the landbased sector. At the higher skilled end, linkage of engineering capability into the BBSRC Advanced Training Partnerships scheme would be valuable. It is of course vital for all levels in the delivery of engineering technologies that basic skills delivery from schools, particularly at primary level, is enhanced.

Opportunities exist to strengthen the UK investment in agricultural engineering research to meet the engineering challenge of global food security. This can be complemented well by inputs from other engineering disciplines to the complex challenges associated with biological targets and agricultural systems. This requires *the establishment of a research theme or platform for 'engineering for agriculture' that can compete on equal terms with other research communities and is appropriately managed* (**Recommendation 3**).

Industry has the capability to work alongside science in the successful exploitation of ideas, though the small scale of R&D in some sectors creates particular challenges that need to be addressed. The farming industry can also benefit, given the value already demonstrated by engineering innovation in cross sector topics like soils and crop protection.

The translation of research into practice also requires further strategic reassessment. The goal is *to encourage the farming industry and the agricultural engineering business community to work with the innovators and educators to establish an appropriate focus for innovation that brings together the needs of agriculture, novel engineering and business opportunity* (**Recommendation 4**). Bringing the innovators and scientists together with engineering businesses and the farming industry will enhance the value of investment in research and education. The identification of a means to voice agricultural engineering priorities in key stakeholder forums will assist this process. A commitment from industry to engage with this in a partnership approach will be vital.

Delivering this value will also require sustained partnerships between industry (both engineering and farming) and the research and education sectors, so that the UK gains full benefit, not just for the farmer, but also for the environment, the food chain and the global consumer. It will be important for all parties to recognise this, and IAgrE will seek to facilitate these partnerships. The impact of ICT and sensors, precision farming and systems optimisation, and advanced understanding of the interactions between machines, processes, biological systems and the environment will be enormous, and we must ensure that the UK is well placed to deliver results.

1. The context – global food security is a priority programme for the UK with multi-agency involvement

The Foresight Report "The Future of Food and Farming"[1] highlights the impact of a number of pressures on the global food system, and pinpoints five challenges (balancing future demand and supply sustainably; addressing the threat of future volatility in the food system; ending hunger; meeting the challenge of a low emissions world; and maintaining biodiversity and ecosystem services while feeding the world) that will need to be met if major stresses to the food system are to be anticipated and managed. The key public sector stakeholders in food and agriculture have recognised the importance of addressing these challenges, and have established a multi-partner Global Food Security (GFS) programme. This is a cross-Council priority for the Research Councils, through the UK Cross-Government Food Research and Innovation Strategy, and has been identified as a target for challenge-led innovation and research in the Government's Innovation and Research Strategy for Growth[2]. It is stated that these Challenge-Led Programmes "can only be resolved through interdisciplinary collaboration, across technological and sectoral expertise, involving both fundamental and applied research"[3]. The Global Food Security Programme Strategic Plan 2011-16[4] reflects this requirement, identifying the importance of chemical engineering, process engineering, electronics and other engineering disciplines to deliver beneficial impacts.

[1] The Future of Food and Farming: Challenges and choices for global sustainability. The Government Office for Science (2011)

[2] Innovation and Research Strategy for Growth. Department of Business, Innovation and Skills (2011)

[3] ibid p20

[4] Global Food Security Programme Strategic Plan 2011 - 16

2. The challenge – agricultural engineering is an important discipline for innovation and delivery of solutions to a wide range of food security challenges, and needs to be recognised as part of the UK strategy

The Institution of Agricultural Engineers (IAgrE) is the professional body for engineers, scientists, technologists and managers in agricultural and allied land-based industries, including forestry, food engineering and technology, amenity, renewable energy, horticulture and the environment, and is recognised as such by the Engineering Council and the Society for the Environment. This report highlights the value of agricultural engineering as a key contribution to the global food security agenda, and indicates gaps in the UK resource base in this area.

Agricultural engineering is an applied scientific discipline, often narrowly associated with farm machinery, but actually now much wider, embodying systems approaches to assess overall impacts through life cycles, and addressing key questions associated with the interface between agriculture and the environment, and global concerns for environment, food supply and people. It has contributed extensively to soil management, land development, mechanisation and automation of livestock farming, and to the efficient planting, harvesting, storage, and processing of farm commodities. This wider view has led to the subject area being increasingly referred to as agricultural and biosystems engineering.

The agricultural engineer recognises the importance of multidisciplinary approaches to deliver solutions, and brings to the partnership expertise in tackling problems at full scale, in real time and on real-life systems, together with a good understanding of the underlying biological system and the implications for practical application. The approaches used share much common ground with environmental concerns, and the development of methods and systems to deal with complexity and uncertainty is a major scientific challenge. Agricultural systems are often sensitive to many environmental variables, and solutions frequently involve understanding, monitoring and controlling complex processes in order to improve productivity and minimise environmental emissions and impacts.

Engineering innovation in agriculture has been a major driver for the advances in global food production and efficient distribution. The American Society of Mechanical Engineers has recognised agricultural mechanisation as their 4th most important achievement in the 20th century, after the car, Apollo and power generation. But the vision of the future for agriculture suggests that there is not only a major opportunity but a real demand for further innovation and its translation into practice. Advances in sensing, optical recognition, robotics, data management, control engineering, mechanical engineering, and mechatronics for example will all feature in solutions to the global challenges.

The ability to deliver solutions requires partnership between key stakeholders to draw in key science and technology, and an engineering voice is needed *to fully recognise the contribution of engineering in meeting societal challenges in global food security and contributing to economic growth* (**Recommendation 1**). At present there is no mechanism in the UK Research Councils for research on critical aspects of physical science and engineering that can deliver innovation in relation to agricultural systems. BBSRC take the lead on agriculture[5] but currently have little involvement with engineering aspects. EPSRC, though supporting food engineering research, do not address engineering for agriculture[6]. The recognition of the global importance of food security gives an opportunity to reassess how the strength of the UK engineering community, both agricultural engineers and other engineering disciplines that can contribute new insights and approaches, can be better linked in to appropriate opportunities for agriculture. If this can be addressed now, there is scope for a sustainable community of engineers to be developed to support future initiatives.

The research base is an important source of innovative understanding and ideas. Past successes and new concepts are illustrated in a series of Case Studies that are provided at the end of this report. Each has a message for the future. The strategic value for the UK can come from

- translation of understanding and innovation in engineering science into high value technology through UK businesses,
- enhanced competitiveness in the UK agriculture and food chain,
- facilitating value from advances in other agricultural disciplines that require new engineering for their implementation
- facilitating value from advances in other engineering sectors by translating their technology into tools and techniques that can work effectively in the challenging environment of agricultural production, processing and supply
- strengthening the engineering sector through training and education at all levels in UK schools, FE, HE and professional development
- sustaining and strengthening UK's position as an international centre for education and training in advanced and sustainable agricultural systems.

[5] UK Cross-Government Food Research and Innovation Strategy (2010), p60

[6] ibid p64

The importance of engineering in any joined up approach to the future of agriculture is fundamental. For example, history shows the strength and value of innovation in harvesting systems as more productive cultivars are produced, the importance of understanding pesticide application technologies to meet concerns over off-target and bystander contamination, the role of sensing and control in the advance of high productivity protected-crop production systems and the scope for engineering to impact on livestock production by advancing building design, milking systems and pollution control. The future, as captured by the Foresight Report, envisages complex problems: continuing demand for more food, but less land available; continuing volatility in global food prices impacting mostly on the poor; global hunger remaining a priority issue; low emissions being demanded so that agriculture does not impose excessive environmental burdens; and an integration of goals on biodiversity and ecosystem services with our approach to managing food production and the land. Tools, techniques and approaches for delivering complex objectives, and responding to quantitative goals, are fundamental to engineering.

The Foresight Report promotes the concept of Sustainable Intensification - maximising food production efficiency by raising yields without using more land, while adapting to climate change, reducing resource inputs and emissions, and maintaining biodiversity and ecosystem services. The goal is to balance crop, livestock, fisheries and agroforestry systems, so that surplus inputs are avoided and soil fertility and ecosystem services are not compromised, while production and income are increased. This provides an obvious demand for engineering and systems approaches to achieve such balance and to optimise performance while delivering the intensification that engineering has demonstrated it can do.

It has been recognised for many years by key players in the farming and food sector that agricultural engineering does not have the key stakeholder champion that it needs. This is a point of strategic importance if global food security is to be seen as a real UK priority. Engineering input must be an integral part of the strategic debates for the sector, and effective ways of linking the engineering research base to the key challenges must be sought.

3. The vision – UK engineering research and innovation can contribute improved agricultural productivity and sustainability in the UK and globally, through new insights and implementation of improved agricultural systems and technologies

This vision for future farming systems highlights opportunity areas in science that can deliver future technologies. The science can develop both from underpinning advances in engineering disciplines *per se* and from cross-disciplinary research.

The range of physical science and engineering disciplines that can make a substantial contribution is wide and this table is only indicative:

	Wider science								
Application	Mathematical modelling	Sensors	Remote sensing	Nanotechnology	Fluid dynamics	Soil physics	Data mining and pattern recognition	Robotics	Surface chemistry
Product quality	●	●						●	●
Environmental pollution	●	●	●		●	●			
Logistics	●							●	
Environmental control	●	●			●				
Irrigation management	●	●	●		●	●			
Fertilisers and pesticides				●			●		●
Within-field precision		●					●	●	
Selective harvesting			●					●	
Postharvest management		●							
Livestock systems	●	●	●	●	●		●	●	
Soil and water management	●	●	●		●		●		●

Improving agricultural efficiencies

Automatic Steering

The Challenge

Along with the introduction of new technologies comes increased operator fatigue as the need to monitor many parameters leads to information overload.

The Solution

Using satellite guidance (gps or global positioning systems) permits automatic steering leaving the operator to focus on equipment and performance.

This leads to immediate and tangible benefits including:

- Elimination of overlaps/underlaps
- Savings in fuel, time and costs
- Reduced machine wear
- Reduced operator fatigue
- Reduced soil compaction with fewer tracks
- Controlled traffic farming
- Better crop establishment

Depending on the gps system used, accuracies within 1 cm are achievable.

Similarly the ways in which engineering advances will demonstrate their impact is very varied, and the list below serves to highlight opportunities:

Precision crop management

Crop selection

- 2D and 3D scanning image analysers undertaking field phenotyping, the assessment of qualitative and quantitative agronomically important traits, will improve selection of crop cultivars

Crop management

- New sensing techniques will provide real time information on key attributes of the crop (nutrient levels, presence of disease or difficult weeds) and the soil (water and nutrient supply)

- Intelligent interpretation of information, using crop and system models will provide early warning of risks and offer mitigation strategies

- Understanding of spatial variability of crops and soil and responsiveness to inputs, will be integrated into effective spatially variable crop management, to maximise productivity and minimise wastage of inputs

Pest and disease control

- In-plant or in-canopy biosensors will provide early warning of pest or disease outbreaks

- Further enhancements to the optimisation of chemical application, through novel atomisation and improved spray handling, will ensure target coverage and efficacy is maximised and losses to the environment reduced

- Mechatronics and automation concepts will offer scope to undertake crop management tasks with autonomous machines, including the identification and eradication of difficult weeds by non-chemical means

Operations and traceability

- Advanced irrigation and drainage control will provide methods to maximise the accurate targeting of limited water supplies, and ensure that risks of runoff and pollution are minimised so soil resources are retained for the crop

- Machine movements and crop management logistics will be optimised so that damage to soil is reduced and localised

- Crop quality sensing in real time at harvest will allow harvest time to be optimised and sorting to be integrated with the harvesting process, where robotics systems will become increasingly available

- Embedding intelligence into the design and operation of machines will allow sensor information to be combined with the knowledge of the farmer and land manager as part of automating processes and operations in the food chain

Precision livestock farming

Animal management

- Animal monitoring using machine vision, environmental sensors, acoustic monitors and gas detectors will provide scope for expert guidance and decision support for animal management both in the field and in housed systems

- Data mining and novel analytical techniques will be developed to ensure that real-time data can be immediately translated into useful management information

Health and welfare

- Biosensors will be actively used for monitoring key health and welfare indicators in real time.
- Animal growth models, coupled with observations on the performance of individual animals, will provide early warning of health or welfare problems and support optimisation of nutrition and environmental conditions

Housing and environmental impacts

- Novel building and ventilation design will enhance the control of ventilation and the aerial environment for the animal
- Robotic systems for handling and management of animals to improve productivity and welfare
- Environmental control will be coupled to waste handling and management systems to reduce greenhouse gas and other emissions and reduce energy use in housed systems
- Advanced chemical engineering methods will improve waste treatment, maximising water and nutrient recycling, thereby minimising pollution risks

Intelligent postharvest and supply chain

Food safety and quality

- Real-time quality sensing and management of supply to the market will be used to maximise the value of perishable products through to the consumer
- Wireless monitoring of perishable goods to predict produce characteristics leading to reduced wastage
- Real time detection in the supply and handling chain of organisms that can cause food poisoning or spoilage to optimise food hygiene systems
- Novel technologies, such as the use of nanotechnologies in food packaging to prolong product shelf-life

Traceability

- Integrated supply chain control will maximise the effectiveness and value of traceability processes

Enhanced translation of knowledge and technology into practice

Standards

- Further standardisation of databus technology and hardware systems will ensure that new sensors and processors can be more rapidly integrated into farm operations

Capabilities

- Intelligent interpretation of data in real time will be user-friendly and more readily applicable to management decision-making
- Use of mobile telephony and apps linked to markets and databases will enhance the ability of the developing country farmer to optimise produce value
- Real-time transmission of data between machines (telematics) for automatic decision-making, on machine management will be widespread, with benefits for productivity, logistics, fuel efficiency and emissions

Training

- Use of CPD concepts and professional technician input throughout farming systems will increase confidence in new technology

4. The evidence – justification of vision through examples of successes and future prospects

The agricultural engineering community in the UK has been actively addressing a wide range of problems to provide better understanding of agricultural systems and to deliver new and improved technologies that will increase productivity, reduce unwanted environmental impacts and optimise system performance. Five case studies are given in Appendix 1, chosen as indicative of the breadth of issues being addressed. All have featured multidisciplinary studies and close working with agricultural engineering businesses, academic researchers (both engineers and biologists) and farmers.

CASE STUDY 1: Computer vision and machine guidance for weed control

Computer-based image analysis provides the capability to evaluate structural and quality parameters of a scene and then use the information to control machines and processes. The demonstration of how this could be used for controlling an unmanned vehicle in an agricultural field has been translated into a commercial product for rapid non-chemical weed control – a computer vision-guided hoe. Immediately taken up as a solution to weed control in organic and horticultural crops (where herbicide approvals are limited or absent), this implement has already established a significant UK and worldwide market. New technologies can widen its application and value.

CASE STUDY 2: Robotic milking leading to precision livestock management

Robotics and sensors have been demonstrated to provide improved production within animal management systems, through the development of the voluntary (robotic) milking systems. Wider use of sensors can improve the welfare of animals and reduce environmental emissions and impacts. Biosensing in particular has enormous potential to address health and welfare issues, when integrated into well-engineered systems.

CASE STUDY 3: Arable crop sprayer technology – delivering novel technology and systems

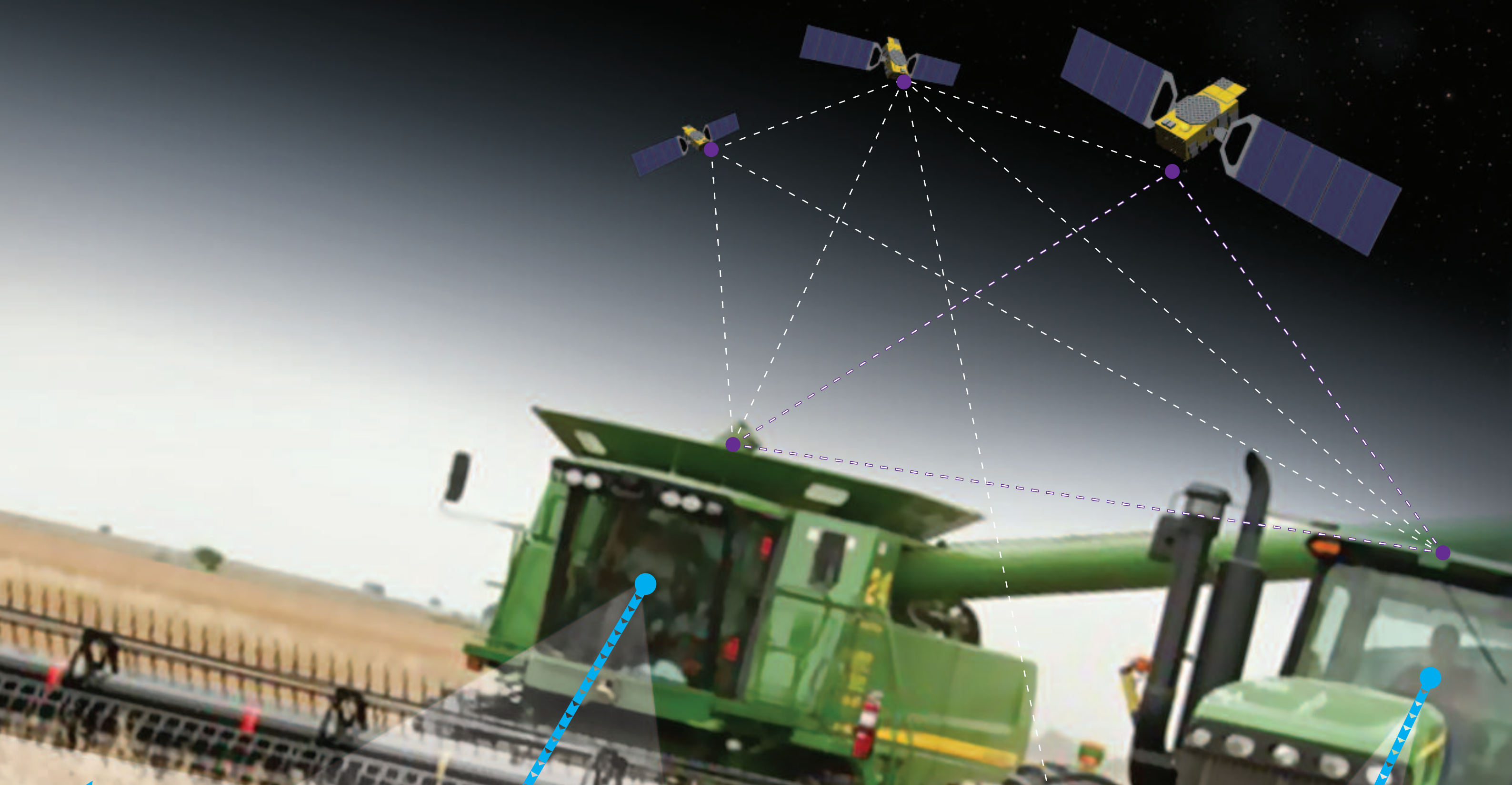
Pesticide efficacy and safety are being improved through new technologies and systems based on an understanding of fluid flow and dispersal in the natural environment. The UK industry has been at the forefront of adoption of new approaches to pesticide application, increasing precision and efficacy, and decreasing off-target risks by factors of two and more. Engineering research underpinning standards and providing innovative technologies has the potential to reduce pesticide use by a further factor of two, and respond to new demands as crop production systems and biological challenges change.

CASE STUDY 4: Machines for soil management

Soil damage by heavy vehicles has been an issue for the last 50 years, but new approaches are now being researched and adopted that can substantially reduce the problem, with benefits in improved productivity, less energy use (for tillage) and much increased rainfall infiltration (reducing the risk of run-off and environmental pollution). Controlled Traffic Farming confines wheelings to 25% or less of the field, and can give 10 to 15% more yield and less fuel use, while fourfold increases in infiltration have been achieved in some environments. Research on machines, systems, tyre-soil interactions and environmental impacts can lead to wider uptake of this and similar methods of sustainable land management.

CASE STUDY 5: Conservation agriculture: the future of smallholder farming

Soil quality is a critical factor globally, and translating understanding of how to manage soil into viable practical systems will benefit food supply and the environment. This is particularly true of the challenges facing subsistence and small-holder farmers in developing countries. Conservation Agriculture is a suite of practices for sustainable intensification, emphasising soil cover with organic matter, minimal soil disturbance, and good crop and cover-crop rotations. Effective implementation requires a new look at sustainable mechanisation in these communities, providing an integrated approach to sustain local manufacturing and provide mutual support right through to the farmer.



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- Savings in fuel, time and costs
- Reduced machine wear
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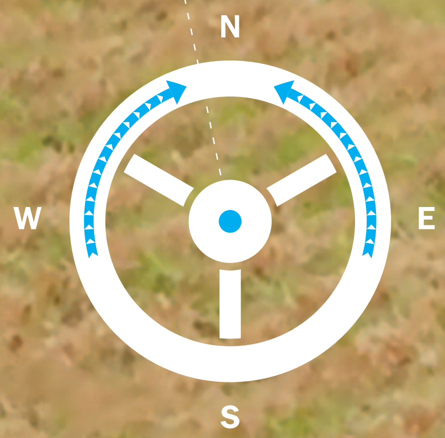
- Reduced soil compaction with fewer tracks
- Controlled traffic farming
- Better crop establishment
- Accuracies within 1 cm depending on the gps system used.



CASE STUDY 6: Improved soil Management to Reduce Runoff and Flood Flows

Water retention capacity of soils can be enhanced by a variety of affordable measures that can make a significant difference to peak flood flows, whilst contributing to improving water quality through reduction in siltation and diffuse pollution and enhancing nature conservation and fisheries interests.

5. The benefits – outcomes that can be expected from realising agricultural engineering advances, for key stakeholders

The opportunities for engineering contributions to advance global food security will come from the new approaches and technologies indicated in the vision section, together with more integrated approaches to putting existing knowledge and technologies into practice, both at home and internationally. Engineering innovations and research alongside advances in biological science will provide many novel ways forward. Some examples of the benefits from advances in agricultural engineering systems that can result are given here, using the challenges of the Foresight Report as a framework.

Challenge A: Balancing future demand and supply sustainably

Engineering innovation is going to be a critical contributor to delivery of agricultural outputs under the imperative of sustainable intensification. Translating knowledge into practice is a major benefit from a strong engineering sector, from science through to the maintenance and management of equipment on the farm. New science and innovative technologies will open up new practices that will both increase production and reduce or reuse waste streams.

A1: Enhanced crop productivity and quality through precision farming advances. Developments in precision farming are already supplying considerable insights into the variability of current production systems (yields can vary by a factor of two in different regions of the same field) and the scope for more precisely controlled input (at scales down to a few metres or individual plants) to deliver benefits in increased productivity, reduced inputs and lower environmental impacts (see Case Study 1). Timings and quantities of fertilisers and pesticides can be adjusted to match current crop state locally, and can be coupled to predictions of future changes in growth rates or disease pressure. The techniques will influence future advances in application technologies, and in crop management regimes that are adapted to minimise GHG emissions from soils. Better planning and scheduling of machine operations has the potential to reduce costs by 25%.

A2: Improved animal health and welfare through real time monitoring and diagnostics. Real-time monitoring and interpretation to highlight risks to health and welfare can improve productivity and quality, while also addressing welfare and environmental impact issues (see Case Study 2). Biosensors to identify changes in physiological state or exposure to pathogens will become feasible for use in intensive systems, and even in extensive ones through the use of remote tracking and monitoring systems. Improved dairy cow fertility management through oestrus sensing has been estimated to be able to deliver 15% reduction in methane emissions, for example.

A3: Better use of irrigation water to support production. With increasing demand for food, and climate change generally making rainfall less reliable, the role of irrigation in food production will inevitably have to increase. However this raises serious challenges due to the competition for water resources. A primary focus of irrigation engineering will therefore be the delivery of systems that are both more efficient and more robust, and globally will emphasise systems that use relatively small amounts of water to support rain-fed farming rather than smaller areas of total irrigation. Three focal points are:

- Integrated water resources for protecting robustness: Interlinking alternative water resources (surface water, groundwater and reservoir storage) whether by pipes, canals or natural water courses; increased on-farm water storage

- Integration of Information and Communications Technology (ICT) with agricultural engineering. Rapid advances in ICT promise methods for both conserving water and increasing production through better control of the transfer and delivery of water, for example: real-time control of gravity canal systems to ensure the correct volumes arrive where and when required; accurate metering and distribution of water in pressurised (piped) networks; automatic control of in-field distribution systems (e.g. sprinklers) for precision irrigation to increase uniformity and accuracy.

- Irrigation systems designed for supplementing rain-fed production: where rain-fed production is possible, relatively small volumes of additional water can have much higher returns. However design and management is more complex and requires: control systems that encourage beneficial use of rainfall; soil management technology that encourages deeper rooting and increased water holding capacity; development of robust low cost mobile systems.

Challenge B: Addressing the threat of future volatility in the food system

Volatility comes from macro-economic and political issues, but increased focus on information and intelligence at all stages in the farming and food cycle will help identify when conditions may be heading towards such difficulties. Increasing efficiency across the food chain will increase buffering of stocks.

B1: Better understanding of the impact of changes in regulation or incentives through the development and use of farm systems models. The government-mediated shifts in production when biofuels became a priority highlight the importance of understanding all the strands in the production systems and ensuring that decisions on optimal approaches do not neglect secondary effects. Agricultural engineering studies incorporate life cycle assessments and other modelling tools, and have previously highlighted risks associated with pesticide taxes and other measures that might have positive environmental goals but be very blunt instruments when trying to achieve those goals. Such integrating studies are already showing the constraints on manipulating agricultural systems to meet emissions goals and can also support new approaches to delivering value from all harvest outputs, with waste streams being able to contribute to soil sustainability and energy production within food production-driven farming systems. Systems models and operational research provide scope for clear assessments of the impact of new technologies on sustainability ahead of the introduction of new technologies, and can link directly to the challenges associated with the delivery of sustainable intensification[7].

[7] Achieving food security in the face of climate change. Final report from the Commission on Sustainable Agriculture and Climate Change. March 2012 p29

[8] Mrema, Baker and Kahan (2008). Agricultural mechanization in sub-Saharan Africa: time for a new look. Agricultural management, marketing and finance Occasional Paper 22. FAO

[9] EPSRC Village E-Science for Life project

B2: Enhanced scale and quality of commodity storage to buffer supply and reduce volatility. The basic principles for effective management of postharvest systems are well-known, but there are still major failings in all parts of the world. Implementation of existing technology, supplemented by current advances in ICT systems that allow integrated systems of monitoring and remote fault identification offer new opportunities to enhance the success of effective storage regimes, and encourage more investment in facilities that will provide buffers against local or regional disruption of supply. Technologies to provide dedicated energy supplies, through solar energy or other local generation, can ensure that resilient systems are available.

Challenge C: Ending hunger

Three quarters of the world's one billion extremely poor people live in rural areas and are dependent on agriculture and its related activities for their livelihoods. They face a series of interconnected natural resource management challenges, and are in the front line of climate change impacts. Global support for agricultural sustainability is not just a matter of addressing only the poorest farmers. It must also address sustainable support systems for production methods that are accessible to poor farmers, as well as improving infrastructure and information systems within an efficient market for inputs and outputs. Agricultural engineers have worked closely with aid agencies, national and international research and extension agencies, and NGOs in developing technologies that have maximum local benefit. Key areas in recent years have been postharvest systems, soil management particularly in relation to water harvesting and soil sustainability (conservation agriculture), chemical application, and ergonomics, which can have great value especially to ensure that technology is well matched to labour availability and particularly gender issues. As economies grow, transition through mechanisation and intensification offers opportunities for improved management but can also lead to poor practice. This can be through inefficient use of agrochemicals, poor soil and water management, and inefficient use of tractors and machinery, all of which could pose significant risks to sustainable farming systems. Agricultural engineers have a vital role to play alongside natural scientists in ensuring that sustainable agricultural systems are developed that can feed the world.

C1: Sustainable advances in subsistence and stakeholder farming through Conservation Agriculture, appropriate mechanisation and improved infrastructure and support. Smallholder and subsistence farmers are the key to food production in developing countries, producing 80% of the food grown in Africa and Asia. Conservation Agriculture (CA), a suite of practices developed to provide sustainable cropping intensification whilst protecting and enhancing the natural resource environment, is described in Case Study 5. The agricultural engineering challenge is to promote local industries and nurture the nascent agricultural engineering sector in developing countries. Recent discussions and reports[8] have highlighted the need to re-examine the value of and approach to mechanisation in sub-Saharan Africa.

Other technologies will also provide access to information and markets. Sensing methods can provide guidance on optimal management of resources, for example using a sensor device that gathers data on air temperature, humidity, air pressure, light, soil moisture and temperature. This information is crucial to making key agricultural decisions about planting, fertilisation, irrigation, pest and disease control and harvesting[9]. Mobile telephony is opening access to market information and improved post-harvest decisions. Investment in infrastructure by governments and in supply chains by the private sector can provide the momentum for real change.

C2: Empowerment of women and communities through appropriate ergonomically-optimised engineering. Engineering has already recognised the importance of ensuring technologies match the capabilities and systems of the user. This is a vital step in empowering people and addressing gender issues relating to both existing and new technologies.

C3: Reduced wastage in food supply chains through appropriate technology and education. Existing knowledge and technologies for postharvest and food chain management of commodities have the potential to deliver significant reduction in wastage, with parallel impacts on economic returns and food availability. A major shortcoming is the availability of technical training and appropriate management support to provide robust and resilient systems.

Nurturing the world’s resources

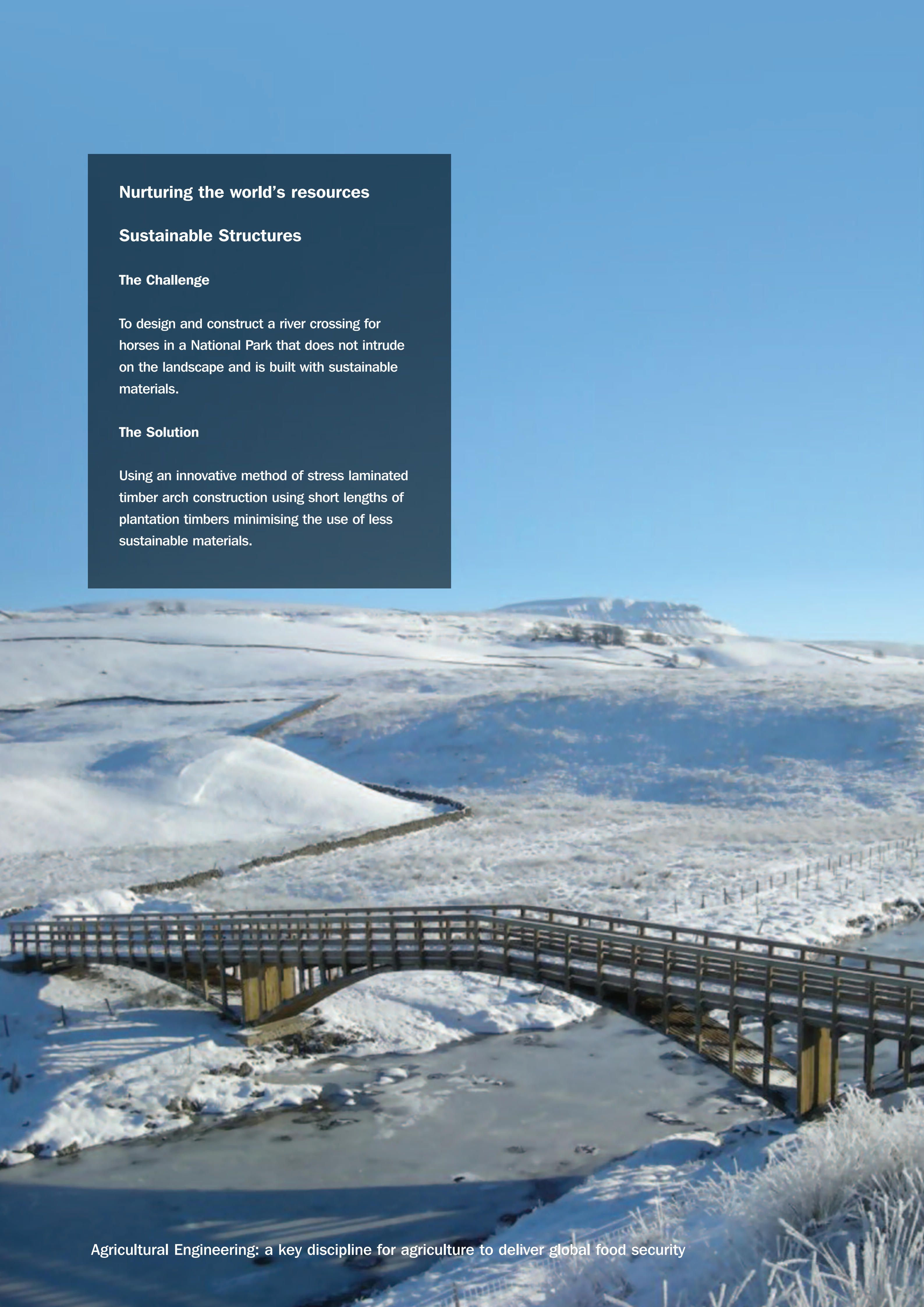
Sustainable Structures

The Challenge

To design and construct a river crossing for horses in a National Park that does not intrude on the landscape and is built with sustainable materials.

The Solution

Using an innovative method of stress laminated timber arch construction using short lengths of plantation timbers minimising the use of less sustainable materials.



Challenge D: Meeting the challenges of a low emissions world

Renewable energy production, energy use for land management and environmental control and emissions from the biological processes on which farming depends are all integral parts of the global farming scene, and it is clear that concerns about energy demand and climate change require that improvements are made. Engineering advances to optimise performance will be crucial if agriculture is to play its part in averting damage to climate and environment. The complexity of farming systems makes an interdisciplinary approach to these problems essential, and combinations of new biological concepts and new engineering technology are needed.

D1: Reduced emissions from livestock and other waste while maximising crop nutrient value Integrated approaches to the management and handling of wastes, both on farm and through cooperative actions with other waste generators, have the potential to enhance the return of plant nutrients to the land, minimise liquid and gaseous emissions of pollutants, including greenhouse gases, and also to provide on farm energy, e.g. through anaerobic digestion and pyrolysis. Effective management of livestock waste seeks to maximise the utilisation of plant nutrients and soil improvement whilst minimising the risks of pollution and damage to the soil through compaction. This requires increasing precision in terms of application timing relative to soil conditions, plant growth stage, and the potential for water pollution. More precise placement within the soil and closer matching of nutrient supply to plant requirements will decrease pollution risk.

Utilisation of sensing methods, ranging from simple physical methods to use of near infrared spectroscopy or hyperspectral reflectance analysis, can determine the nutrient content of the waste stream before land spreading, or even in real-time during land spreading, so that application rates can be matched to local crop nutrient requirements within the field. Application systems need to be optimised to ensure that the manure is placed appropriately in the soil to control losses of key gases such as ammonia or nitrous oxide, and ensure rapid nutrient availability to the crop. High capacity distribution machinery will allow timely application within narrow periods when crop requirements, soil conditions and the demands of regulation come together.

D2: Reduced energy use in farm machines through improved engines and power management. Agricultural tractors and self-propelled machines rely heavily on the diesel engine for motive power, but impose different requirements from those of other diesel uses, making economy and exhaust emission control more challenging. These differences include higher load cycles, more sustained and often continuous full power operation and cooling concerns due to slower vehicle speed and often dusty operating conditions. Fuel economy has become a major concern to the industry, following rapid prices increases, and is now keenly in focus. In addition off-road exhaust emission regulations are being implemented in all EU countries. Due to the unique operating conditions within agriculture, more sophisticated and expensive technologies have been adopted to meet the legislation. The result is that new tractors and machines are very economical and clean, though at considerably increased cost. In addition to engines, manufacturers have been developing machines and perfecting systems with a keen focus on productivity, economy and reliability. Many changes have taken place in transmission design, for instance with auto shifting multi-speed or infinitely variable transmissions, with considerably reduced parasitic power losses than in the past. Sophisticated hydraulic systems with power on demand and minimal energy requirement when idle are now the norm. However the single most important contribution to efficiency and economy has been the development of electronic control, not only of vehicle systems such as engine, transmission, hydraulics but more importantly the inter connectivity of all them such that total vehicle function and economy can be maximised. An example would be when travelling at a fixed road speed to allow the transmission to speed up and the engine to slow down to reduce fuel consumption, emissions and noise. Further, the introduction of GPS systems for the guidance and control of agricultural tractors and machines, and current developments in telematics where vehicles communicate with each other and the farm office, have the potential to provide further increases in productivity and reductions in fuel usage and emissions. Automatic steering is already delivering 10 – 15% reductions in use of fuel, fertiliser, seed and operational time, and automatic machine control at headlands can accelerate this time-consuming step by 30%.

D3: Ability to predict major interactions between management methods and emissions for intelligent regulation. Mathematical modelling of farming systems has demonstrated the value of investigating how changes in practice, often with an objective of improving the environmental footprint of farming, can result in counterintuitive negative impacts through the ways in which farmers will react to maximise profits, and the limitations of manageable regulatory instruments. Continued development of these approaches will deliver benefits to policy makers by highlighting issues in areas such as life cycle impact, scope for pesticide reduction, and the value and damage associated with shifts to biofuel production.

Challenge E: Maintaining biodiversity and ecosystem services while feeding the world

The competing requirements of preserving biodiversity and the environment while enhancing productivity present an opportunity for the implementation of advances in farming systems. Technologies that improve precision and control in farming will have immediate potential to reduce unnecessary impacts. Understanding the interaction between management processes and farming systems, including soil and water processes, will ensure that proposed novel or adapted technologies can deliver real benefits.

E1: Reduction in pesticide applications and off-target losses. Advances in application methods and the use of precision farming technologies will be critical to the delivery of a smaller footprint for pesticides on the countryside and natural communities, both as point source and diffuse pollutants, and as risks to bystanders and operators (see Case Study 3). Understanding how delivery can be made more precise and dispersal off-target can be minimised will be a continuing challenge. The opportunity for plant scale operations, suggested by current developments in weed control within Case Study 1, is just one area in which engineering advance will deliver benefit.

E2: Enhanced soil quality through better control of land management. The impact of machinery on land has been highlighted in Case Study 4. Better understanding of how to minimise damage and to retain soil quality through optimal operations can enhance soil quality and energy use reductions of 10 to 15% have already been demonstrated. Effective management of residues and no till techniques can encourage higher returns of organic matter to the soil, with consequent benefits for water retention and productivity.

E3: Improved surface water management and drainage to reduce flood and pollution risk. New work on drain design has the potential to minimise undesirable effects of run-off and through-flow without compromising crop performance. US studies of ‘controlled drainage’, controlling drain outfall and hence field water table levels, has significantly reduced nitrate in discharge waters. Surface drains could now be designed to minimise any obstruction to field operations, and be used to manage run-off and filter solid materials in ways that can enhance natural habitats. Grassed areas, constructed wetlands and other storage areas might also be linked to irrigation reservoirs. The practice of reducing runoff rates through local detention storage to reduce peak runoff rates in upland areas could, with development, be extended to other grassland areas. This should be feasible, without major effects on grassland productivity, by controlling both surface and subsurface drain discharges. Scope also exists in some lowland grassland areas to utilise these as temporary flood storage areas, allowing the peak flow in the main drainage channel to be reduced.

Minimising soil Compaction

Rubber Tracked Machinery

The Challenge

Increasing machinery and implement weights can result high in high ground contact pressures with resultant soil damage particularly in unsuitable ground conditions.

The Solution

Replacing wheels with rubber tracks spreads the machine load over a much greater area and can give a higher level of tractive efficency over a wider range of soil conditions.

6. The delivery – current state of play in UK agricultural engineering, including the industry and education and training, what is missing and what needs to be achieved to deliver the vision

This report has demonstrated the opportunities for, and the inherent capability of, agricultural engineering to contribute significantly to the challenges of sustainable food production and global food security. If the UK is to play its part in this global challenge and secure commercial opportunities, the relevant skills and resources must themselves be sustainable and 'fit for purpose'. This section reviews the current state and capacity of these resources and the potential for their future supply in the UK. At present these resources are inadequate and support from key stakeholders would stimulate the sector and encourage future success.

Engineering capability contributes across the continuum from knowledge generation and innovation through system and component development, translational research, knowledge transfer to application, commercialisation and maintenance. Typically those with postgraduate training take on roles aimed at the provision of new knowledge using scientific methods, and have the ability to take on leading roles in translational research, knowledge transfer and senior management within commercial enterprises. Graduates are often involved in product and system development, knowledge transfer and marketing. Technical skills are at the heart of the sector and are essential to the development, testing, application and maintenance of any engineering system. Innovation can arise at any stage and from any skills set.

The need for this expertise to interact both vertically and horizontally with other disciplines and interests is fundamental to achieving successful outcomes from problem definition through to applying a commercially viable solution. In many cases agricultural engineering is at the heart of providing relevant skills and capabilities to enable these connections.

An effective education, training and professional development system is essential to securing the provision of skills to address both advancing technology and the wider application of agricultural engineering in the future. There are no recent formal analyses that can provide data on the anticipated levels of supply and demand for these human resources. Our appraisal therefore is based on a combination of the limited data that could be accessed within the scope of this report and the experience of the contributing authors.

The value of the UK Agricultural Engineering Sector

The agricultural engineering sector underpins UK food production and contributes to the provision of a range of non-food services with equipment and systems for conserving natural resources, controlling pollution, enabling the management of environmental capital and mitigating the impact of weather and climatic events.

The UK has retained a strong reputation for the quality and relevance of its agricultural engineering equipment and expertise. This has had a direct impact on UK business, and an indirect one through education and training in many countries with developing economies. The legacy of past investment in training of students from developing countries is increasingly at risk, but there remains an opportunity to revive and develop this platform both as a basis for diplomatic goodwill and to address food security, water conservation, labour use and other economic, environmental and social issues.

When considered alone the annual domestic market for farm and related outdoor machinery is some £2.5 billion and the value of exports is £1.8 billion. This represents about a 4% share of global sales. Technical support services relating to the use of machinery, and soil and water management are also substantial; there is a large domestic market for these and they earn important export income. In total, agricultural engineering is an important direct contributor to national income as well as supporting the wider UK agricultural sector, which yields more than £20 billion of production to give net farm income of £4.6 billion.

Since 1990 the UK agricultural machinery sector has experienced structural change. It is now led by the development and production of lower volume, higher value, specialist machines, such as back-hoe loaders, self-propelled sprayers and crop establishment tools, whereas it was previously dominated by high volume tractor manufacture. A small number of global manufacturers of high volume machines (e.g. tractors, combine harvesters, balers, forage harvesters) have emerged from industry consolidation e.g. John Deere, AGCO, Claas, but none of these have UK-based global R&D facilities, while only one (CNH) has an assembly plant. The exception is JCB which has continued as a fully integrated and globally-leading player in specialised agricultural as well as construction machinery. The loss of high volume machine R&D and manufacturing is regrettable and essentially irreversible: it reflects a wider loss of international competitiveness due in part to weak public investment in relevant R&D, infrastructure and human resources. However, parts of the sector remain dynamic and innovative and with strong potential in higher value machines and supporting components, including those based on sensor and data fusion capabilities. There are also many SMEs capable of grasping opportunities to take advanced technologies into practice. Action is needed to prevent the loss of this innovative capacity, and the human capital associated with it, as other countries begin to recognise the importance of agricultural engineering in their approach to tackling global food security.

Reliable information on the value of consulting and other technical services delivered by the agricultural engineering discipline is not available. Export income is thought to be substantial, considering the extensive involvement of UK firms and engineers in irrigation, mechanisation and agricultural resource management projects. In addition to services supporting production, agricultural engineers provide valuable expert advice on food storage and transport.

In conclusion, the requirement for massively increased global food production is certain to drive the size of the global market for agricultural equipment and engineering services. Mechanisation is arguably the most important factor in increasing production in the developing world and the result will be rapid and sustained growth in markets for agricultural engineering. Meeting this market demand with innovative products should be a national priority to address global food security and increase national income. Against this background, and with appropriate policy development, the UK has a credible platform from which to re-emerge as a global leader in advanced engineering technologies to contribute to this valuable sector.

Resourcing the challenge

The maintenance of this sector and the realisation of the opportunities that we have indicated require a supply of high quality researchers, educators, innovators, developers, entrepreneurs, communicators and technicians along with appropriate facilities. We therefore need to develop education, research and training in engineering for agriculture (**Recommendation 2**). This will need to be achieved against a background of limited public investment in applied R&D and education for agricultural engineering, especially since the 1990s. Notable events have been the closure of Silsoe Research Institute (the National Institute of Agricultural Engineering), the closure of undergraduate University Departments (e.g. at Cranfield and Newcastle, in part driven by the withdrawal of funding for overseas students) and a steady decline in all important FE provision. Moreover the Research Councils have not given any emphasis to engineering for agriculture, with BBSRC grant-awarding structures dominated by bioscientists and EPSRC largely excluding agriculture.

Research capacity in the UK aimed at generating new knowledge and developing research skills for agricultural engineering is at a low point. This can probably be best judged through provision for postgraduate students. Through their studies, they are not only key providers of research within the University sector but are also the future teachers in higher education. Annual throughput in studies directly related to agricultural engineering is now typically 25 postgraduate students. Sponsors and educational institutions are reporting increasing difficulty in attracting suitably qualified candidates committed to the UK beyond qualification. Fifteen years ago there would have been about 60 postgraduate students qualifying annually, 10 with Doctorates, 10 Masters Degrees by research and 40 taught Masters Degrees. This was supplemented substantially by researchers from other engineering and physical science departments, strengthening the capability for the sector. Mechanical, electrical and process engineers have demonstrated that they can contribute strongly to the sector when working alongside others with experience and understanding of agricultural problems and challenges. Agricultural engineering brings together the engineering method with an appreciation of interacting biological systems in agriculture. Capacity for agricultural engineers to contribute strongly to the research programme needs some rebuilding.

Graduate agricultural engineers are required as developers, teachers, and communicators; they are usually the link with other disciplines and often take on senior commercial roles. Harper Adams University College is now the sole UK provider of undergraduate agricultural engineers with a typical output of 60 graduates annually, 40 of whom pursue careers in agricultural engineering. The undergraduate intake has now reached 90 students which is near capacity, and further provision is now needed if this welcome upturn is to be sustained and improved. IAgrE is already stimulating and supporting bodies seeking to provide appropriate education and training, and should develop and sustain this activity. The reputation for agricultural engineering teaching in the UK was also very important for passing skills on to those in developing countries. This contribution is still highly regarded round the world, and such a reputation has a positive impact on the relationships with those farming communities. Reinvigorating the education sector will also provide value to the UK international development and aid programme.

High quality technicians are required with an extensive range of skills and 'state of the art' expertise, as the technology used in landbased engineering is as advanced as that found in any other engineering sector and has many differing applications. There are currently in excess of 500 vacancies for engineers/technicians in the landbased engineering sector. This situation is not unusual and is significant for a small engineering sector[10]. In this respect agricultural engineering is part of a more widely recognised problem. Following an 18 month review, a recent report[11] has identified that across the wider UK engineering sectors, there is "*an alarming skills gap between the number of technicians in the UK and the 450,000 higher skilled jobs that will be needed by 2020 to boost growth in the economy and ensure the UK maintains a competitive edge internationally*". It is safe to predict that the rising demand for technicians with increasingly high levels of skill required to meet the sustainable food production challenges will exceed supply and that attention must be applied to address the potential deficit.

[10] Search return for Agricultural Engineers (UK) on the Indeed UK web Jobsite. 08/04/2012

[11] Report for the Technician Council (26/03/2012) (http://www.professional-technician.org.uk)

Nurturing the world's resources

Precision Mobile Drip Irrigation

The Challenge

Applying irrigation water accurately and efficiently to a crop without expensive permanent in-field irrigation installations.

The Solution

Combining drip irrigation with a mobile centre pivot irrigator means that water can be applied precisely where it is needed. Losses to wind and evaporation are minimised which can result in exceptional irrigation application efficiencies (>90%).

Add the continuously variable speed of a hydrostatic wheel drive transmission together with computer based irrigation scheduling and yield increases and reduction in water used can be expected.

IAgrE has been highlighting its concerns about this developing situation over the last decade and, in conjunction with the AEA, has a good understanding of the situation, its causes and potential remedies. IAgrE, working with its partners from industry, has developed an industry accreditation process with the aims of promoting professionalism across the sector, improving retention within our sector by providing a clear career path and ironing out the differences among the variety of generic qualifications on offer.

Thus, based on a range of generic underpinning qualifications, this accreditation scheme (Landbased Technician Accreditation or LTA scheme[12]), administered by IAgrE on behalf of industry[13], recognises a range of industry-based training courses and maps them against the Engineering Council's Engineering Technician (EngTech) qualification. This gives individual technicians a professional qualification that is recognised not only across the UK engineering sector but also internationally. Now in its fifth year, this scheme recognises some 2,800 individuals across 4 tiers, 150 of them registered at EngTech. In 2012, a further adjunct to this scheme (the LTAMEA scheme[14]) was introduced for those working on milking equipment. Although a much smaller segment of the sector, there are already in excess of 200 registrants on this scheme most of whom will qualify for EngTech registration. There is anecdotal[15] evidence that technician retention has increased as employers recognise the need to set improved pay scales in place.

In the Food Research Partnership report on High Level Skills for Food[16], there are similar concerns about the need for very high level skills for agriculture and food, though engineering is not mentioned. The conclusions in that report supported the establishment of the BBSRC Advanced Training Partnerships, to create sustainable formal collaborations between users and providers of high–level skills in the agri–food sector. There are strong arguments for similar interactions in engineering technologies for agriculture, particularly as we see novel sensors and ICT advances being increasingly taken up by this community.

It is recognised that there are some encouraging signs of emergent renewal in facilities, such as new investment by Harper Adams University College in teaching and research, including the National Centre for Precision Farming, and by Cranfield University in the form of £4m of soil, water and terramechanics research facilities to replace those at the former Silsoe College. These initiatives are being funded within existing budgets, supplemented by philanthropic support, and not as a result of a strategic shift in public policy.

Of course there is also an important general concern underlying any forward look for engineering and technical employment and that is the importance of addressing numeracy at primary and secondary level in our education system. As Engineering UK have noted[17], research from the Department for Education[18] shows that, among those who achieved high grades at A Level, there is a persistent dependence on strong prior attainment in a subject from the end of primary education. Considering this, we believe that maths and science specialist teachers in primary schools are critical if children are to reach their potential in primary school and beyond.

Overall we anticipate the need for a well-focused and carefully justified increase in the provision of UK-based research and educational resources to support engineering for sustainable food production and that, wherever appropriate, these should be operated in partnership with complementary expertise, facilities and markets. We perceive some risk in allowing the market to be the sole informant of future needs. This is especially the case for those processes that have a long lead-time, such as Higher Education and the need to account for some significant revival of the market arising from the opportunities set out earlier. Careful strategic assessment is required to select the main priority areas where reliance on the market alone may not deliver robust, sustainable solutions.

[12] Landbased Technician Accreditation scheme for field and associated equipment. www.iagretech.org

[13] IAgrE works together with the industry trade bodies AEA and BAGMA to deliver these schemes.

[14] Landbased Technician Accreditation scheme for milking equipment. www.ltamea.org

[15] Conversations (IAgrE CEO) with LTA 4 technicians

[16] High-level Skills for Food. Report from the Food Research Partnership Skills Sub-Group. January 2010

[17] Engineering UK (2012). The state of engineering

[18] Primary science and mathematics education: Getting the basics right, Royal Society, 2010, p3

Obtaining the resources

We have argued that there is a significant deficit in the capacity required to meet the challenges and opportunities. Each of the potential sources of additional resources is now assessed in broad terms with indications as to how these may be more effectively applied to this sector. As with all the other issues, these have varying degrees of interaction and cross linkage that need to be recognised and fostered. It will be important for the key stakeholders to review how they can influence an integrated and effective programme to stimulate this sector. The multi-partner Global Food Security programme needs to take stock and share views if the systemic changes that have diminished agricultural engineering are to be overcome in a sustainable way. IAgrE will seek to facilitate and support steps to achieve this progress and would welcome interest and input from other parties.

Research Councils have the responsibility to support the provision of primary knowledge. Agricultural engineering is not just the application of technology but requires new concepts that can work in challenging situations (e.g. new sensor technology for remote and hostile environments, and interfacing with living objects). Perhaps more important is that agricultural engineering is frequently the mechanism that enables the application of new science to agricultural systems. There is good evidence for the value of engineering expertise, at various levels of sophistication and engagement, into the whole process from problem definition to application. Agricultural engineering is one of the few engineering disciplines requiring a detailed understanding of biological systems as well as engineering and physical science. Ten years ago, there was extensive and productive engagement of many university engineering departments in collaborative projects addressing agricultural targets and there is scope to reinvigorate this. The biological complexity and variability of these targets and the challenge of real time working in hostile and natural environments generated new engineering insights of considerable technical value. This broader view of the engineering contribution is complementary to the agricultural engineering discipline, and each can contribute new insights and approaches to global food security targets.

The BBSRC, with support from EPSRC in engaging with engineering, should recognise the potential value of the opportunities outlined in this report and *establish a research theme or platform for 'engineering for agriculture' that can compete on equal terms with other research communities* (**Recommendation 3**). The absence of a programme in this area for many years means that there are few mid-career scientists based in agricultural engineering with any track record in winning RC funding, which suggests that some early-career focused Principal Investigator development may be needed.

Government and EU research budgets. The food research and innovation landscape encompasses a range of Government departments, Devolved Administrations and other public bodies, including the majority of Research Councils (RCs), the Technology Strategy Board (TSB), the Higher Education Funding Councils, and a diverse industrial base. Agricultural engineering can be a relevant contributor and needs to maintain interactions with these stakeholders. Equally this expertise can have a key role in informing the formulation of regulations, especially the feasibility and practicality of various options - the design of pollution control and pesticide application regulations are good examples.

Agricultural engineering features in the EU Framework programme and is recognised in the ERA community. The German agricultural engineering society (VDI-MEG), with the European society EurAgEng, led the development of a strategic programme of agricultural engineering priorities in Europe, with broad support from many countries. This input was coordinated under the European Technology Platform MANUFUTURE, and has generated a number of Framework projects, with some UK involvement. There is also an active ERA-NET network, ICT-Agri, to strengthen European research in the area of ICT and robotics in agriculture through transnational cooperation, and UK is now a potential participant as Defra has joined the second call for collaborative projects this summer, making £350k available for appropriate participants.

Technology Strategy Board has become the focus for joint government industry projects, following the closure of the Defra LINK programmes. These projects are generally collaborative in nature, with industrial and academic participants, with total government assistance being generally limited to around the 50% level. So far both the TSB's calls for agricultural projects have had some scope for engineering involvement, and there is potential for more within the Sustainable Agriculture and Food Innovation Platform, though engineering for agriculture may not be a priority. The small R&D capacity of agricultural engineering businesses in the UK does not fit easily with the TSB model, and some further steps may be necessary to encourage further engagement of this sector through TSB.

The Agricultural and Horticultural Development Board has a particularly strong role in supporting translational research and knowledge transfer activities in which agricultural engineering has an important part to play. A number of important issues such as soil management, pollution control, reducing GHG emissions, crop protection, grassland management and animal welfare occur across sectors, with engineering capable of a significant contribution. Again we encourage AHDB to identify these cross-sector issues and involve agricultural engineers in understanding the problem and developing solutions.

Charities may have modest resources but can make a key contribution by stimulating initiatives, bridging gaps between the private and public sectors in critical areas. The Douglas Bomford Trust, the principal charity operating in this area, is closely connected with and has a good understanding of these issues and has provided critical funding to sustain the sector over the last decade. Though limited, such philanthropy is to be welcomed but we are now urging other stakeholders to contribute resources to this area. Many agricultural research charities collaborate under the umbrella organisation the Agri-Food Charities Partnership (AFCP) which exists to help smaller research charities co-ordinate their efforts.

Businesses have demonstrated commercial engagement in specific projects, through LINK/TSB co-funding and some direct funding of near-market projects, but there needs to be more engagement with major farm equipment companies. All the large multi-nationals spend a great deal of money on R&D (one as much as $1million per day) and we need to work more closely with them to support major strategic pre-competitive research. The scale of the sector and competitive pressures make this the most likely way for the future as well. It should be acknowledged that the industry does engage closely with IAgrE in other areas, including professionalism and technician training.

The somewhat fragmented nature of the resource base is likely to mean that opportunities are missed through lack of a shared vision for enhanced technology transfer. There needs to be serious consideration of how innovation and technology transfer can be effectively coupled and resources best used to engage with business and demonstrate successes to the farming community. We need to *encourage the farming industry and the agricultural engineering business community to work with the innovators and educators to establish an appropriate focus for innovation that brings together the needs of agriculture, novel engineering and business opportunity*

(**Recommendation 4**). The identification of a means to voice agricultural engineering priorities in key stakeholder forums will assist this process. A commitment from industry to engage with this in a partnership approach will be vital.

Appropriate Technology

Post Harvest Handling and Storage

The Challenge

The cooking tomato commonly known as Pomme d'Amour is considered the most important vegetable grown in the northern part of the island of Mauritius and is an important part of the traditional diet.

Almost all the crop is grown by small farmers for their family and to sell in the local markets with two or three harvests a year.

Local solutions to problems are often rough and ready but only require modest changes in practice to achieve major effects. Traditional handling methods resulted in post harvest losses through mechanical damage, moisture losses and disease damage impacting adversely on fruit sale price.

The Solution

Here, a traditional inappropriately sized deep wooden box constructed from rough sawn timber is replaced by a relatively cheap alternative. Shallower open sided smooth plastic crates stored off the ground on wooden pallets resulted in reduced mechanical damage, lower storage temperatures and improved moisture content.

In the field, the crop needed to be harvested and put in the shaded immediately and covered as it was brought to the farm.

The result: The eventual percentage of top price fruit was increased to 60% from 25% and the cost of the plastic trays paid for in one to two harvests depending on the market price.

7. Key messages and practical actions needed

Recommendation 1: To fully recognise the contribution of engineering in meeting societal challenges in global food security and contributing to economic growth

The agricultural engineering community have actively communicated the importance of engineering to the advance of agricultural productivity, and to wider issues of natural resource use and protection. IAgrE, as a member of the 'Engineering the Future' alliance of professional institutions and national organisations in engineering, will press for an enhanced engagement with government, particularly on strategic needs for engineering for agriculture. Agricultural engineering provides a critical interface for new technologies to be implemented to benefit the food chain and food security. The forums on global food security would benefit from this engineering input.

Possible actions

1.1: The engineering community, with proactive input from IAgrE, should work together to ensure that the key opportunities to promote the role of engineering in agriculture are taken.

1.2: Lines of contact with key stakeholders should be established by this community, to provide contributions to policy development and consultations on global food and farming issues.

Observation

Agricultural progress is recognised globally as a multidisciplinary challenge and there are many examples of strong cross-disciplinary coordination in other countries and communities to draw on.

Outcome

The agricultural engineering component will be more integrated into the analysis of issues, the development of solutions and the identification of priorities and resources, so that policy outcomes will better meet the challenges of achieving sustainable farming and food.

Recommendation 2: To develop the important opportunities for education, research and training in engineering for agriculture.

There is a current challenge in the supply of engineering expertise into all aspects of UK industry at all levels. This will necessarily impact on the progress of new engineering technologies to deliver advances into the food and farming sector. Enhancement of capacity for graduate and postgraduate education and training in engineering areas relevant to farming and food can be stimulated by recognition of the challenging science and societal value in this sector. More education capacity can also include overseas training provision. This has in the past been a prime source of agricultural engineering knowledge and capability throughout the developing world, with implications for the future UK support of global agricultural development.

Possible actions

2.1 IAgrE should work with other professional and public bodies to facilitate links between agricultural engineering and the wider engineering community, particularly to strengthen the training base for good graduate and postgraduate engineering for agriculture.

2.2: Agricultural engineering training for key specialists from developing countries has significant potential value for the development agenda.

2.3: The Advanced Training Partnership approach could be extended to include agricultural engineering.

Observation

The IAgrE has demonstrated the value of recognising and encouraging professionalism in the technician community, and is seeking to broaden the recognition of agricultural engineering in the wider engineering community. Other opportunities for universities to support engineering aspects of agricultural engineering training are being pursued, with potential to strengthen research interest. It may be necessary to work with the providers to establish scope for expansion of provision, rather than relying solely on market signals.

Outcome

Engineering capability to support agriculture and related businesses will enhance the uptake of new engineering and information technologies delivering improved productivity, quality and environmental protection. Strengthening the education provision will also link these skills into delivery of support to developing country needs where translation of engineering into practice will be increasingly valuable.

Recommendation 3: To establish a research theme or platform for 'engineering for agriculture' that can compete on equal terms with other research communities and is appropriately managed.

Generally the topic area of engineering for agriculture has not had a strong identity in the deliberations and funding decisions of the Research Councils nor with the agricultural industry-funded levy bodies, which tend to be production-sector orientated. At present BBSRC has no body of physical scientists and engineers to provide peer review and ensure high quality research is funded. Technology Strategy Board initiatives generally require significant commercial investment, but the limited R&D capacity within the community of agricultural engineering businesses in the UK tends to restrict their participation in these programmes. Consequently the generation of new knowledge required to underpin innovation, for example in new sensor technology and informatics, has been constrained.

Possible actions

3.1: Engineering for agriculture could provide a focus for research and innovation to address the challenge-led nature of the GFS programme. An 'engineering for agriculture' programme would need to engage with the UK engineering research base to establish and sustain a community contributing high quality research.

3.2: Further development of approaches to encourage the participation of smaller companies, and of businesses outside food and agriculture that have relevant innovative capability, would enhance the scope for innovation in new engineering technologies for agriculture.

3.3: Identifying and developing approaches to 'cross sector' issues, many of which have a strong engineering dimension, would be a valuable focus for applied research with direct benefit to the agricultural industry.

Observation

Though BBSRC have lead responsibility for agriculture, their limited involvement currently with the engineering community will pose a challenge in developing a committed body of strong engineering researchers who can ensure that a sustainable programme of engineering for agriculture can be established. Support from the EPSRC in identifying and encouraging areas of common interest would be of considerable value. IAgrE have the potential to network across businesses and facilitate stakeholder events relevant to TSB or levy bodies.

Outcome

The UK's acknowledged strength in engineering research will address agricultural problems and challenges, providing a flow of new concepts to support advances in global food security and intellectual property into UK businesses.

Recommendation 4: to encourage the farming industry and the agricultural engineering business community to work with the innovators and educators to establish an appropriate focus for innovation that brings together the needs of agriculture, novel engineering and business opportunity.

This report has argued that engineering has many new advances to offer to the challenges facing agricultural systems. Agricultural engineering is providing new precision technologies and, together with other technological advances, these will offer new integrated solutions to global challenges. Defra should understand, embrace and promote these technologies for their ability to deliver environmental benefits whilst enhancing production efficiency. There also needs to be clear recognition by the farming and agricultural engineering business community that their active participation is necessary if this is to be pulled through. Incentives to drive this in terms of fiscal policy to encourage greater industrial investment in R&D should be considered. Success in this may require not only technical innovation within the sector, but also strong commercial and project management skills. Both physical and virtual centres of excellence may need to be considered in relation to the translation of engineering innovation into practice. Effective commercialisation of new approaches is often hampered by legislation which is poorly understood by the innovator. Dialogue between regulatory authorities and research groups will help maximise the impact of innovation, as regulation often delays the commercialisation of new concepts.

Possible actions

4.1: A mechanism to communicate agricultural engineering issues, opportunities, systems and technologies across key stakeholders should be established to promote the value from enhanced activity in engineering for agriculture.

4.2: Industry partnerships with key players in research and education will be needed to sustain progress and demonstrate tangible benefits.

Observation

It is widely recognised that market mechanisms alone are unlikely to sustain the breadth of activities that are needed in relation to improved global food security, because of fragmentation of the agricultural sector and existing market failures. The benefits to the UK economy through improved farming systems may not trigger directly investment and innovation in advanced engineering systems, nor the knowledge base for appropriate light touch regulation. Partnerships within the wider stakeholder community may help identify how value can be best achieved and IAgrE will seek to facilitate this. The AEA and NFU could have important roles in defining how these partnerships might be established.

Outcome

A sustainable approach for translation of new technology into practice will ensure that there is the greatest likelihood of UK gaining full value from innovations in engineering for this sector, and consequently making a full contribution to advances in global food security.

Appendices

Appendix 1: Case studies

Appendix 2: Glossary of terms

Appendix 1 – Case Studies

Case Study 1:

Computer vision and machine guidance for weed control

Strong collaborations between agricultural engineering research and university engineering groups from the late-1980s underpinned the development of computer-based image analysis as an effective technology for the control of mechanisation and automation of biological systems. The variability of biological targets and their environment provided new challenges that required real innovation. Out of these partnerships, a range of innovations in machine vision were generated with impact on autonomous vehicle operation, animal management, vegetable sorting and weed control.

The capability to accurately interpret crop scenes in varying natural lighting conditions was initially demonstrated through real-time control of an autonomous vehicle negotiating rows of vegetables. The implications for management of inputs to vegetable crops were then translated into projects with industry support, showing how a research tool could be translated into a practical method to manage weeds.

Implementation of this technology and its extension to a wider range of target crop/weed combinations has been paralleled in the last decade by commercialisation through partnerships with UK businesses active in the area. The first product has been a vision-guided hoe for mechanical control of weeds. The demand for such technology has been considerable. Organic farmers utilise hoeing as one of the few acceptable tools to control weeds, but needed faster work rates and better accuracy. But conventional farmers also had major problems as the tightening of pesticide approval procedures had led to withdrawal of effective selective herbicides for crops like carrots. The technology is of particular relevance to carrots, onions and leeks, with an annual value of £0.25 billion in the UK.

The engineering science was considerable, having to deal with the challenges of sun and shade within images, recognition of crop rows in heavily weed-infested scenes, controlling the hoe to deal with weeds in the row not just between crop rows, and meeting the target operating speeds that could make the tool commercially viable whilst minimising the risk of crop damage. The result has been a successful technology translated into a product that is generating attention and sales.

The innovation team, operating as a small business, continues to provide the new ideas and technical insights, and works with commercial partners to ensure that the implementation is robust and reliable. The commercial partners have delivered into UK and overseas markets (leading to a Queens Award for export achievement in 2010 for Garford Farm Machinery) with sales exceeding £2m within three years of commercialisation. New scope for innovation is still being identified, including plant scale operation utilising minimal quantities of pesticides to difficult targets, drawing in other expertise in novel pesticide applicators to complement this very different approach to weed control[19]. This plant-scale spot application can reduce herbicide use by 95%.

[19] National Horticultural Forum. Research into Use: The Strawberry and Brassica Crops. April 2011

Improving agricultural efficiencies

Computer vision for the precision control of field machines

The Challenge

The high costs and logistics of using human labour for weeding operations have become prohibitive.

Traditional mechanical weeding is not always accurate and often results in crop damage.

Farmers are under increasing pressure to reduce the use of an ever decreasing number of herbicides.

The Solution

The use of machine (computer) vision has been successful in accurately mechanically weeding both in-row and between rows.

Recent developments have demonstrated how computer vision can detect weeds and target herbicide application so that overall volumes can be significantly reduced with no loss of efficacy.

Appendix 1 – Case Studies

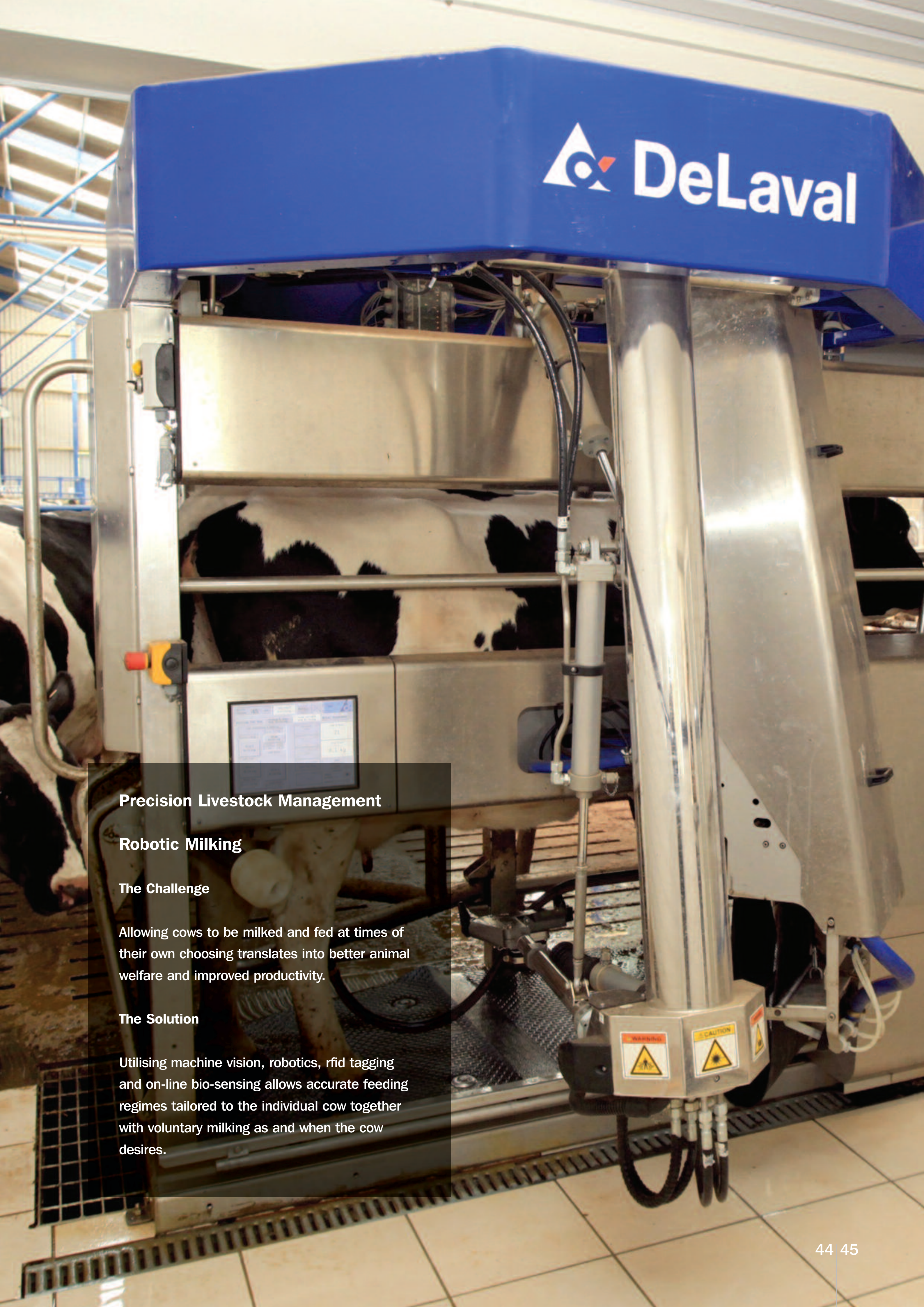
Case Study 2:

Robotic milking leading to precision livestock management

The invention of the single arm robotic milking system by British research engineers in the early 1990s opened a new era in automated management of dairy cows. The choice of a pneumatic arm gave a machine that was more compliant, suiting the sensitive interactions between machine and animal. Robotic milking permitted cows to be milked and fed at times of their own choosing, which translated both into better animal welfare and improved productivity. Once the herdsman/farmer was relieved of the repetitive task of milking, they could focus on animal husbandry issues (such as foot condition and artificial insemination) that are often overlooked under the time pressure of long hours in the pit of a milking parlour. Routine human observation of the cow can also be greatly enhanced by the development of novel sensing systems such as on-line biosensing for compounds in the milk, potentially indicating the health and fertility status of cows. UK research engineers have also developed the wireless rumen-monitoring bolus, the cow breath sampler and the wireless lameness-monitoring collar. These systems can be a major asset to the management of the modern high production cow, especially to meet the rising standards set for animal welfare.

The opportunities are considerable. Improved monitoring of the dairy cow will reduce feed costs and permit the development of diets high in forage and food sources unusable by humans (wheat tailings, sugar beet pulp etc.) without reducing the enormous potential for high yields. In-parlour and within-rumen monitoring techniques have the potential to address methane emissions monitoring, which amount to a 5% loss of feed energy by the cow, and assist GHG emissions reductions. Emerging technologies permit the automatic monitoring of lameness and calving, further reducing losses by disease. On-line monitoring of progesterone in milk to improve insemination management, with better than 80% specificity, would reduce the 300,000 cows slaughtered annually due to the limitations of detecting oestrus by behavioural methods. Keeping fewer young stock as replacements could cut methane emissions from the UK dairy herds by 15%. There is huge potential, especially with the large commercial-minded dairies now in existence, to improve animal welfare and reduce emissions without reducing margins.

The 250 million dairy cows worldwide (FAO, 2010 estimate) provide a ready market for the development and implementation of new technologies. Biosensing implementation needs a large demand to justify the investment in the final stage of R&D, and thus health, welfare and quality concerns associated with the management of dairy cows provide an important opportunity for new sensing technologies. The handling and analysis of the information streams associated with such monitoring will also provide a major technical challenge in information technology, data mining and optimal decision-making. These improvements will come about through integrating sensors, computers and machines.



Precision Livestock Management

Robotic Milking

The Challenge

Allowing cows to be milked and fed at times of their own choosing translates into better animal welfare and improved productivity.

The Solution

Utilising machine vision, robotics, rfid tagging and on-line bio-sensing allows accurate feeding regimes tailored to the individual cow together with voluntary milking as and when the cow desires.

Appendix 1 – Case Studies

Case Study 3:

Arable crop sprayer technology – delivering novel technology and systems

The UK crop spraying community has an international reputation for cutting edge technology from a strong manufacturing base, with good coordination between companies (via AEA) and effective links to world-class R&D (e.g. SSAU, ADAS and HSL). Its reputation has provided a platform for commercial activities in home and overseas markets, and strong input to the development of international standards. Standards development has had close links to development of regulatory instruments (e.g. European Sustainable Use Directive for plant protection products). The ability to support such developments depends on a well-coordinated, technically strong UK base.

The business sector is diverse. There are SME manufacturing companies producing specialised machines with a high technical specification and aimed at both the home and export markets, organisations concerned with sprayer component design and manufacture that are either UK companies or part of a larger multi-national group, both with significant activity in both home and overseas markets and importing organisations that are generally parts of multi-national groups.

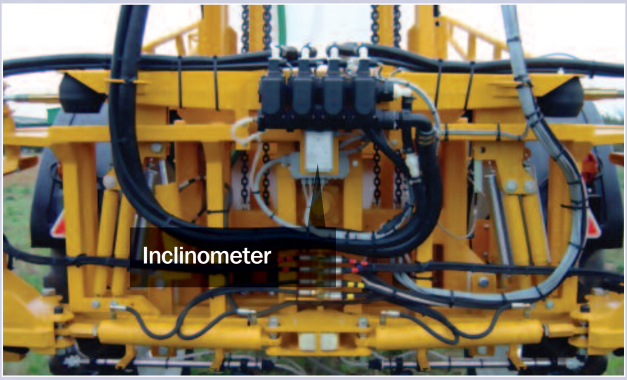
There have been many significant technical developments in the last two decades, often UK led:

- higher work rates by increasing working widths (to 36 m or more), increasing sprayer speeds (to 15 km/h or faster) and operating with lower application volumes (down to 100 l/ha) for timely applications, high product efficacy and hence the minimum quantity of pesticide being used;
- minimising spray drift risk and off-target exposure of waters, boundaries and bystanders. New nozzle designs have 75% less drift risk, and improved booms reduce drift more than 50%;
- higher uniformity within the treated area, avoiding localised over-dosing (with crop damage and the potential for higher residues) and under-dosing (resulting in a loss of control);
- matching chemicals to targets within the canopy (e.g. control fungal disease on ears, influencing crop quality) or in a spatially variable field, including less overlap in non-uniformly shaped fields;
- better machine monitoring and control, for remote diagnostics and automated record keeping.

Key commercial innovations with which the UK community has been particularly involved include:

- air-induction nozzles delivering reductions in spray drift while maintaining good deposits and product efficacy. They now account for more than 50% of spray nozzle sales worldwide;
- boom structures and suspension systems enabling booms up to 36 m wide to be operated close to the crop canopy with the advantages of reduced drift and controlled deposition;
- dose control systems that adjust the amount of chemical applied, responding rapidly to changes in spraying speed or required dose.

This successful sector has responded to the market, and been innovative and quick to adopt and adapt emerging technologies, utilising strategic R&D. Future changes in crop production technologies will set new requirements for crop protection. Equipment will need to match changing farmer needs to sustain domestic and international market share, and a strong technical base must underpin regulatory aspects of agricultural chemical use and address public concerns. The engineering science that has underpinned this includes fluid flow control and atomisation, surface chemistry and particle dispersal in air, and understanding of interaction between particles, wind flows and crop canopies. There are direct benefits to productivity and competitiveness of farming and major indirect benefits through protection of biodiversity, and reduced pesticide contamination of the environment. Further engineering advances in timeliness and targeting can reduce pesticide use by 50%. Developing countries will derive major benefits through access to well-researched technologies.



Improving agricultural efficiencies

Crop Sprayer Technology

The Challenge

Minimising the amount of pesticide needed to achieve a given biological effect whilst protecting non-target organisms (e.g. hedgerows, human residents and bystanders) from exposure to pesticides.

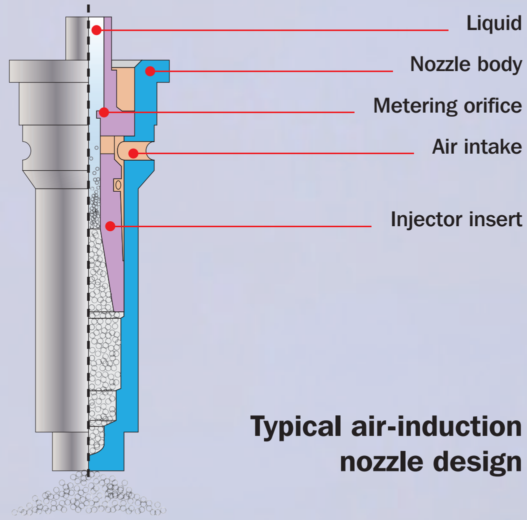
The Solution

Using:

- Appropriate spray nozzle technology (e.g. air intake induction design) that will minimise the risk of drift but will give good target deposition and high levels of product efficacy
- Well designed boom suspension systems with both passive and active elements to maintain the boom at the optimum operating height
- Computer based control systems that adjust output to match variations in forward speed and minimise over-lapping treatments.

Future developments

Will use sensing systems and guidance to identify target and apply chemicals only to the areas where they are needed.



Typical air-induction nozzle design

Case Study 4:

Machines for soil management

UK agricultural engineers, working with international partners, are leading development of farming systems to improve yields and meet environmental and sustainability goals. The challenge is to move away from current largely random vehicle traffic over fields to a more controlled regime. The benefits in decreased soil damage, improved soil water and air transport and better crop growth can be considerable. Yield improvements could be obtained relatively quickly with phased investment in new machinery, if manufacturers can be persuaded to support equipment development. The agricultural industry can mobilise resources to address these issues – but good engineers and applied scientists are needed to develop appropriate systems.

The increasing weight of farm machinery is a cause for concern because soil compaction can impede crop growth and yield, and also reduce water infiltration, leading to runoff, pollution of water courses and enhanced flood risk. This was recognised in the Strutt Report[20], following the disastrous harvest conditions in 1968, and led to research to alleviate and repair damaged soils. Work was conducted on methods to reduce contact pressures and repair compacted soils by improved soil loosening. Unless special care is taken following loosening, by using vehicles with low contact pressures, the soil easily re-compacts and yield benefits are lost. In the 1980s and 90s, gantry farming was developed in the UK, demonstrating the benefits if traffic could be minimised. More recently, following the practice of growing high value root crops in beds to give improved yield and quality, work in Australia[21] on controlled traffic farming systems (CTF) showed improvements in wheat yield of up to 15%. The principle of CTF is to limit wheel tracks of field operations to about 25% of the field rather than the 90% of “conventional” random traffic. This has become easier with automatic steering systems on field machines, and reliable and affordable real time kinetic (RTK) global positioning systems (GPS). In addition to yield increases, the energy for tillage is reduced, simpler more timely tillage systems are possible and improved rainfall infiltration rates of up to 400% have been recorded[22].

Replication of the Australian method, based on 3m track centres, is difficult here due to restrictions on road transport of equipment. A group of leading farmers, working with the organisation CTF (Europe), are developing novel methods to overcome these issues. CTF Europe is seeking to establish a Soil and Water Management Centre at Harper Adams to address a broad range of practical soil and water issues. Their first goal is to address soil compaction by establishing a long term experiment on alternative traffic management systems (conventional random, lower ground pressure and CTF) and alternative tillage operations. The main problems are that machinery must be re-engineered to work within system constraints (e.g. wheel track and harvester widths). For some farm systems, CTF is too complex but reduced contact pressure (LGP) can deliver benefits after further development and communication to farmers. Though improvements in tyre design have been very significant, smarter systems to reduce wheel slip would be beneficial. Rubber tracks have provided significant advances in vehicle manoeuvrability and in overcoming deep compaction[23], but development to reduce peak pressures offers further benefits. Improved design methods and new high-strength materials to reduce the axle load across the range of farm machines can further reduce compaction. Already benefits in yield, fuel use and time of operations of greater than 10% have been demonstrated in the UK.

[20] MAFF (1970) Modern Farming and the Soil, Ministry of Agriculture, Fisheries and Food

[21] Tullberg, G, Yule, D F and McGarry D. (2003) ‘On track’ to sustainable farming systems in Australia. 16th Triennial Conference – ISTRO, Brisbane

[22] Chamen, W C T. (2011) The effects of low and controlled traffic systems on soil physical properties, yields and the profitability of cereal crops on a range of soil types. PhD Thesis, Cranfield University

[23] Ansorge, D and Godwin R J. (2007) The effect of tyres and a rubber track at high axle loads on soil compaction, Part 1: Single axle studies. Biosystems Engineering, 98, 115-126

Minimising Soil Compaction

Controlled Traffic Farming

The Challenge

Unplanned largely random field traffic can result in soil damage over significant areas of the field. Any soil compaction can impede crop growth and yield. It can also reduce water infiltration, which in turn can lead to runoff, pollution of water courses and enhanced flood risk.

The Solution

Use of controlled traffic farming systems (CTF) has shown improvements in wheat yield of between 5 and 15%. The principle of CTF is to concentrate wheel tracks of field operations to about 25% of the field rather than the 90% of "conventional" random traffic.

Appendix 1 – Case Studies

Case Study 5:

Conservation agriculture: the future of smallholder farming

There is little new arable land in Asia and Africa and degradation is advanced and worsening. Smallholder farmers in Brazil and Paraguay, faced with falling crop yields and soil degradation, have concluded that practices must change to stabilise and increase production sustainably: their agriculture must protect natural resources, especially against unnecessary and extremely destructive tillage. We also know that poor practices cause 15% of global emissions of greenhouse gases, as carbon dioxide, methane and nitrous oxide. Conservation agriculture (CA) can play an important role.

Conservation agriculture (CA) is a suite of practices developed to provide sustainable cropping intensification whilst protecting natural resources. It builds on our understanding of soil quality, the importance of organic matter, and the impact of inappropriate tillage for the farmer and the environment and involves site-specific adaptation of three basic principles: keeping soil covered with organic matter, retaining crop residues and augmenting with specially sown cover crops; not disturbing the soil more than absolutely necessary to get seed into the soil at the required depth (no-till agriculture); and applying the well-understood concept of crop and cover-crop rotations and associations, to manage fertility and reduce the build-up of pests, diseases and weeds.

Great steps are being taken in sub-Saharan Africa, Asia and Central America. A major thrust by FAO and others has provided a sound platform for the practice to take off. We know what needs to be done to the soil and the crop. But a major obstacle to greater success is often the immature state of indigenous manufacturing capabilities and sustainable approaches to mechanisation[24]. Local manufacture can respond rapidly to the demands of the agricultural sector, but equipment is not available on the market. Imports tend to be expensive, slow to initiate and unable to adapt easily to local circumstances. Local manufacturers say farmers don't know what they want and anyway they have limited purchasing capacity.

The agricultural engineering challenge is to take our knowledge of soils and implements, and the effects of management and water, and then promote local agricultural engineering industries in developing countries. Guidelines for success in developing the CA equipment industry will include:

- *The need for manufacturers to carry out market studies* working with researchers, farmers, farming organisations, input and credit suppliers and others.
- *The importance of thorough testing of equipment before commercial batch production.* Manufacturers need to incorporate user feedback into the next generation design.
- *The provision of technical training for manufacturers, operators, dealers and extension staff,* including training in business skills and business diversification.
- *Support for hire service providers;* there are increasing efforts to support hire services for tractor or animal traction owners, as high investment costs can often a disincentive for individual farmers.
- *Active promotion of products,* through on-farm demonstrations, field days and agricultural shows.
- *The formation of CA practitioners mutual support groups.*

There is a major opportunity for international aid organisations, with national governments to support the development of indigenous agricultural industries and expand the current 120m hectares of CA not subjecting the soil to damaging tillage. In the long term, cheaper equipment tailored to local needs will be required, and now is the time to intervene with appropriate technical support.

[24] http://blog.cimmyt.org/?p=8198. "Mechanization, entrepreneurship, and conservation agriculture to leverage sustainable intensification in eastern and southern Africa" (MELISA), CIMMYT workshop 2012

Appropriate Technology

Conservation Tillage

The Challenge

Conservation agriculture requires the soil to be kept covered and for seed and fertilizer to be placed with a minimum of soil disturbance.

The conventional plough remains popular but continues to wreak immense damage on agricultural soils.

The Solution

“no-till” planters cutting through the surface vegetation and deposit the seed and fertilizer at the depth and placement required.

Here, a Brazilian animal drawn planter is being evaluated by farmers in Tanzania

Case Study 6:

Improved soil Management to Reduce Runoff and Flood Flows

Water retention capacity of soils can be enhanced by a variety of affordable measures that can make a significant difference to peak flood flows, whilst contributing to improving water quality through reduction in siltation and diffuse pollution and enhancing nature conservation and fisheries interests.

Studies carried out in the Parrett catchment, where rainfall intensities of 4 mm h-1 lasting for an eight hour period (a total of 32 mm) in Bridgwater in December 1999 were taken as an example. Other rainfall during the same day totalled 32 mm; this was in excess of that expected in a one day, one in ten year return period storm and was part of a five day rainfall event, of 62 mm, with a one in two year return period. A similar five day event followed almost immediately. Due to the effect of global warming on total rainfall, it is predicted that there could be an increase of 13 - 22% in the United Kingdom, through either increased intensity or duration.[25]

There is ample evidence from many sources that the infiltration rates of soils in good structural condition are well in excess of the above rainfall intensities and that the runoff would be negligible. Comparison of rainfall and runoff data gathered between January 1997 and December 2000, however, indicate that runoff equal to or greater than the rainfall has been recorded at Chiselborough, Somerset, during winter periods.

This evidence is in agreement with work[26] that demonstrated that extensive soil degradation was found in 64% and 46% of the sites examined by the National Soil Resources Institute (NSRI) in the Tone and Parrett catchments, respectively. This could cause an increase in runoff by up to 25%.

Lowering the water table by 0.5 m prior to the onset of a significant rainfall event would provide storage for 50 mm of water. This would store more water than a one day rainfall event for a one in ten return period or 80% of a five day rainfall event with a return period of one in two years, for the Parrett catchment. This demonstrates the importance of good field drainage in providing the necessary temporary buffer storage by allowing the discharge of antecedent rainfall.

Increasing the roughness of the soil surface by mouldboard ploughing would provide temporary storage for depths of water of approximately 16 mm on flat surfaces, and this would reduce to 10 mm for slopes of 10 degrees.[27]

It is evident that suitable management in upper catchments should ensure that the soils:

- are not saturated at the time of the peak rainfall;
- have the capacity to accept greater rates of infiltration by improved field traffic management of both vehicles and animals, thus minimising surface caps and destroying compaction;
- provide sufficient surface depressional storage to allow time for infiltration; and
- integrate the above with further water retention measures.

These softer engineering practices should then enhance the environment and reduce flooding.[28]

[25] Environment Agency (2002). The Parrett Catchment water management strategy action plan

[26] Palmer R C (2002). Soil structural conditions in the Tone and Parrett Catchments during February and March 2002. NSRI Research Report No. SR 9046V for Environment Agency, 38pp

[27] Edwards G M;Taylor N C; Godwin R J (1984). The influence of soil surface configuration on depression storage, runoff and soil loss. In: Rickson R J (Ed). Conserving soil resources, European perspectives. CAB International

[28] Godwin R J; Dresser M L (2003) Review of Soil management Techniques for Water Retention and Minimising Diffues Water Pollution in the River Parrett Catchment. R&D Technical Report P2-261/10/TR, Environment Agency, Bristol

Improving agricultural efficiencies

Soil management for Flood Control

The Challenge

High rainfall events can threaten both residential and strategically important infrastructure such as power stations

The Solution

Encourage farmers to assist in the management of peak flows by adopting improved soil management techniques

Storage mechanism	Equivalent depth (mm)	Storage volume (x 10^6 m^3)
1. Soil pores to a depth of 0.5 m	50	78
2. Surface depressions for a ploughed field	10	16
3. Drainage ditches	2.75	4
4. 100 detention ponds of 25,000 m^3	1.5	2
Total	64	100

NB 1 in 2 year 5 day event is 62 mm or approximately 100 x 10^6 m^3

After: Soil and Water Management in the Parret Catchment, Godwin and Dresser, 2003

Appendix 2: Glossary of terms

AEA	Agricultural Engineers Association: the trade association representing manufacturers and importers of agricultural machinery and outdoor power equipment (horticulture, professional and leisure grass care and forestry).
AFCP	The Agri-Food Charities Partnership: an independent umbrella organisation which exists to maximise the impact of agricultural research charities.
AHDB	Agricultural and Horticultural Development Board: levy-payer funded organisation which undertakes research and development (R&D), farm-level knowledge transfer (KT) and knowledge exchange (KE) activity in six key commodity sectors: pig meat, beef and lamb, commercial horticulture, milk, potatoes & cereals and oilseeds.
BAGMA	British Agricultural and Garden Machinery Association: the trade association representing agricultural and garden machinery dealers in the UK
BBSRC	Biotechnology and Biological Sciences Research Council
CA	conservation agriculture
CPD	continuous professional development
CTF	controlled traffic farming
EPSRC	Engineering and Physical Sciences Research Council
EurAgEng	he European Society of Agricultural Engineers
FAO	United Nations Food and Agricultural Organisation
GFS	Global Food Security
GHG	greenhouse gases, particularly carbon dioxide, methane and nitrous oxide
HSL	Health and Safety Laboratory
IAgrE	the professional body for engineers, scientists, technologists and managers in agricultural and allied land-based industries, including forestry, food engineering and technology, amenity, renewable energy, horticulture and the environment
ICT	information and communication technology
LTA	Landbased Technician Accreditation
NGO	Non-governmental organisation
SSAU	Silsoe Spray Applications Unit (NIAB/TAG)
TSB	The Technology Strategy Board: the UK's national innovation agency. An executive non-departmental public body (NDPB) established by the Government in 2007 and sponsored by the Department for Business, Innovation and Skills (BIS).


JCB
FASTRAC

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“When the message got out that I had trained at the foremost UK centre for agricultural engineering, and immediately it was identified that I should meet the Minister of Agriculture, and my contribution to the development of all aspects of the farming business was actively sought.”

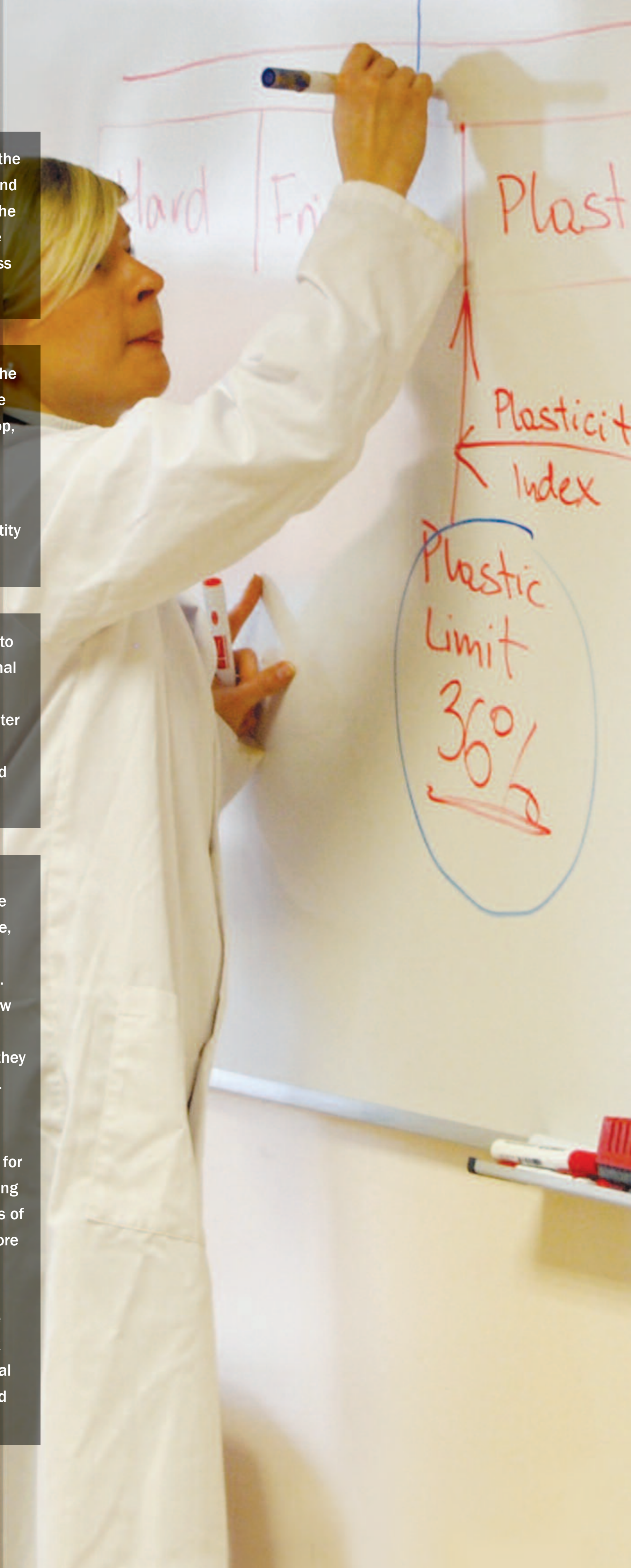
“Consider the case of a grain store where two of the largest agribusiness companies had stored a large quantity of oil seeds. One company owned the crop, the other operated the store. Because no-one understood the technical challenge of storing this crop in quantity, and the equipment was both unsuitable and badly maintained, the entire quantity of seeds was lost. This is not unique.”

A 45 year career in ag-engineering has taken me to over 60 countries with projects ranging from animal traction (donkey and camel ploughing) in Sudan through mechanised irrigation in Iraq to storm water flood relief in Hong Kong. The unique mix of knowledge of soil, water and machines has proved invaluable in problem solving many issues.”

“As an ag-engineer, my role is to improve sustainability of farming enterprises all around the world – not just environmental, but animal welfare, economic and social aspects. Cold winters and extremely hot summers require creative solutions. Shade in paddocks for animals to rest under – how do you do this with an 85 ha pivot irrigator for instance? Trees, which produce cooling effect as they transpire etc., again with a pivot irrigation system. Continuous access to drinkable water!

Ergonomics is important in the dairy, and not just for workers. Well engineered races to minimise walking speed and distances to parlour, also reduce issues of lameness. Quiet milking machines, keep cows more comfortable and feeling safer.

Sourcing milk from developing countries, we have less freedom. Hand milking is prevalent, and milk quality is the issue – time to chilling, effect on final product quality. Infrastructure often dictates speed and education is key.”



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