Nuffield Farming Scholarships Trust

A Horticultural Development Company Award

Intelligent agronomy - growing more for less

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Acknowledgements

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I would particularly like to thank my employers including Andrew Burgess and Simon Bowen for supporting my Nuffield and allowing me the time to travel overseas.

Disclaimer

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1. Executive Summary

EU Directives are already impacting our access to plant protection products which up to the present day have allowed us to produce cheap high quality food (vegetables) reliably. The use and impact of these products has become emotive, political and non-scientific and is resulting in reduced availability of highly effective products to UK vegetable growers. In parallel to this, multinational agrochemical companies are not developing new products and technology for speciality ('minor') crops due to the massive investment required for development and registration.

In addition to this other Directives are starting to bite with respect to fertiliser use and particularly run-off into watercourses. Links to oil prices mean that the cost of fertiliser inputs is very volatile and increasingly expensive. Clearly all inputs into vegetable production (with the exception of sunlight, air temperature and rain) cost money and price pressure on this relatively unsupported sector is massive, particularly since the recession.

I have used my Nuffield scholarship opportunity to investigate growing more for less though intelligent agronomy. I believe this provides a means to deliver both the environmental agenda (demanded by our market) and to ensure that we have the tools to maintain an economically sustainable business in the challenging times of rising input costs and volatile markets. Using countries that face a range of economic and environmental pressures I have assessed how these challenges are being addressed and worked out at a farm level, distilling this knowledge for the benefit and sustainability of UK food producers and informing science funders of suitable areas for future research and development needed to support the vegetable sector.

Two key areas of focus are growing without pesticides and optimising crop nutrition to reduce fertiliser inputs.

My study led me to conclude that our answers lie within four key areas (with examples given):

i. Attention to detail

Crop protection solutions through knowledge transfer and further UK research & development work. Examples:

- Monitoring and Integrated Pest Management, including taking better account of the potentially detrimental side effects of existing approved plant protection products.

- Development of sentinel or indicator plants to identify crop health issues and focus management responses. Satellite information may be able to help in the future to determine crop health.

- Fully understanding the role of naturally occurring beneficial insects in crop protection. Road testing solutions for encouraging biological control in field crops including introducing other plant species e.g. *Alyssum* and Buckwheat.

ii. Application of science

Crop protection solutions through knowledge transfer and further UK research & development. Examples:

- Screening a number of new naturally derived bio pesticide products.

- Devising appropriate methods for evaluating the effectiveness of these products.

- Facilitating an appropriate registration approach for biological plant protection products (currently prohibiting new products to the speciality crop sector)

Engineering solutions through development and demonstration trials, where 'seeing is believing.' Examples:

- Precision farming – understanding the variability within vegetable crops and using this spatial information to target plant inputs.

- Weed management – using image analysis technology to target inputs only where required. Also the screening and registration of suitable naturally derived weed control products.

- Disease management – using ultra-violet light to reduce diseases in crop leaves.

iii. Adaptation to change

- Agronomic solutions through further research and technology transfer. Examples;

- More intelligent use of catch and cover crops
- Quantifying the value of green manures (where use is currently limited by lack of research)
- Presentation of soils and crops as three dimensions as opposed to two.
- Challenging current model of short term rents for vegetable production (economically driven but unsustainable in long term)

- Genetics solutions through breeding and genetic diversity. Examples;

- Breeding varieties under sub-optimal conditions
- Investigation of wider genetic diversity and locally adapted varieties.

iv. Ancient wisdom

During my visit I met a Maori vegetable farmer who promoted locally adapted varieties and helped reinforce my interest in soil health and wellbeing to facilitate plant health and nutrition. Also the study highlighted the importance of lessons from organic production (where there are no quick fixes). Whilst organics are a small part of our production base and will continue to be so, every vegetable grower I have spoken to has learnt something from trying organic production. My recommendation is that more research should take place in organic systems, which will offer benefits to conventional growers in the areas of nutrient, soil and water management and in addition crop protection approaches.

As a result of the study I have integrated my findings into my current in-house development programme. I am presenting research recommendations to my sponsor (HDC), DEFRA and BBSRC, in the hope that further research, development and knowledge transfer will accelerate progress in this area.

Growing more for less using intelligent agronomy: I am convinced that with science and collaboration on our side we can continue to make good progress towards this goal.

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2. Introduction

2.1. High Input Production for Affordable Food

Since World War II a combination of developments in plant genetics (crop varieties), plant nutrients (fertilisers) and plant protection (pesticide) inputs together with improved soil preparation and mechanisation have allowed us to produce food more cheaply than ever before. Fig.1. illustrates how much more affordable food has become over the period 1987-2010 with a 50% reduction in real terms. This is principally due to improvements and efficiencies in crop production.

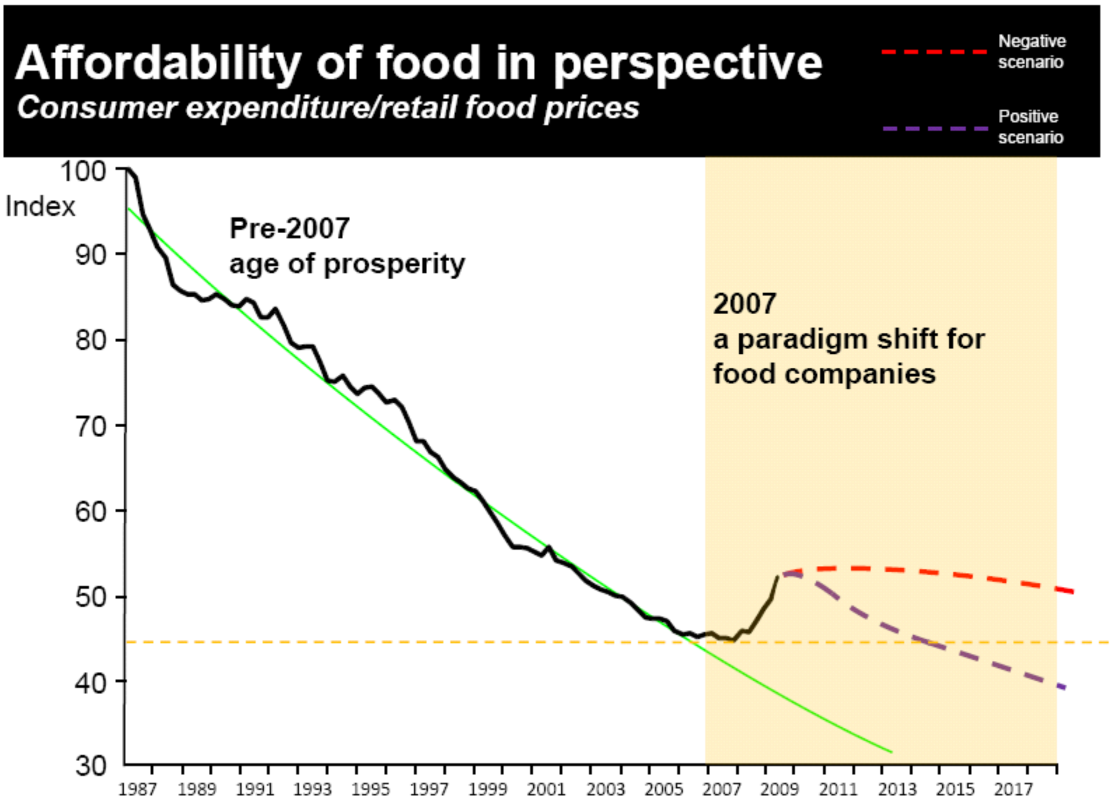

Fig.1. Affordability of food 1987-2010 (Sion Roberts, EFFP, 2010)

Current crop varieties have been bred to respond to high input production systems (fertiliser and pesticides). For example; between 1948 and 2007 winter wheat yields increased by 90%. Fifty percent of this increase was attributable to genetic improvement from 1948-82, and 88% from 1982-2007. The latter period increase correlates with the increased use of nitrogen fertilisers which almost doubled from the late 1970's to the mid 1980s. [1] Pesticide inputs also increased significantly over this period, which have protected the additional plant yield potential. For vegetables the trends are very similar. For example from 1948 to 1985 carrot yields increased by 45% and from 1985 to 2009 by

1 Mackay et al (2010) Theoretical and Applied Genetics.

a further 54%. Brussels sprouts yields increased by 43% and 24% respectively over the same periods.[2]

2.2. Global challenges

This ability to produce affordable food is important particularly given that global food supplies need to increase by 50% over the next 20 years to meet the demands of a growing population.[3] In addition to the UK and North Western Europe, this is even more crucial in developing countries where food inflation is already rife and the poorest are worst affected. For example last year in Niger food prices rose by 25% in under a year in the period up to July 2010.[4] Even poor producers are affected due to the rising costs of inputs, particularly fertilisers.

As food production has intensified there has been increasing concern not only about the rising cost and sustainable supply of inputs but also about the way we farm and the impact this is having on our environment. This is coupled with a growing recognition that our planet (soils, air, water, wildlife, genetic diversity) are finite resources which need careful stewardship. It is now thought that if everyone in the world consumed natural resources and generated carbon dioxide at the rate we do in the UK, we'd need two planets – not just one − to support us.[5]

On top of this current climate forecasters predict that the area suitable for crop production is likely to shrink (good soils with adequate light, temperature and water). However, this should place the UK is a strong strategic position with our excellent soils and enhanced crop productivity due to increased temperatures and CO_2 concentrations, providing we manage our water well (see Fig. 2 which illustrates our strong future potential).

Figure 2 - see overleaf

2 DEFRA Horticultural Statistics and MAFF Agricultural Statistics.

3 ISHS Acta Horticulturae 355: Plant Breeding for Mankind – Symposium Agribex 94. Plant Breeding in improving crop yield and quality in recent decades (V.Silvey) also J Beddington report.

4 http://www.christianaid.org.uk/emergencies/current/west-africa-food-crisis

5 Tasting the Future: Collaborative Innovation for One Planet Food. ADAS, FDF, Food Ethics Council, WWF (June 2010).

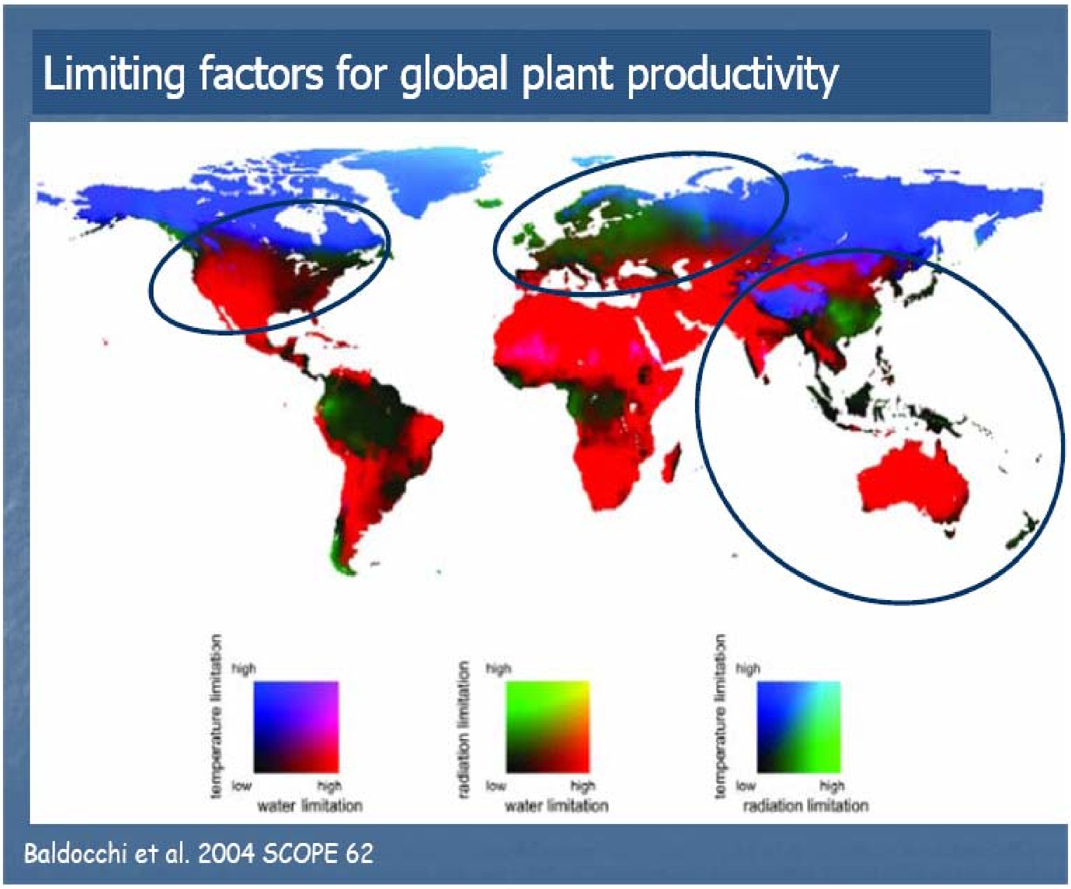

Fig.2. Limiting factors for global plant productivity, (Prof. Ian Crute Presentation)

2.3. UK Field Vegetable Sector

Mindful of our successes to date and our need to respond to these global challenges, this study focuses specifically on the technology and input-intensive horticulture sector in which I work and which contributes significantly to the UK economy. Agriculture and horticulture have a combined Gross Value Added (GVA) of £5.5 billion pa. An estimated 1.4 billion (22%) comes from horticulture (vegetables, flowers, fruits and ornamentals).[6] The value added per unit of output is higher for horticulture (45%) than for agriculture, due to the short, value-adding, efficient, highly productive processes involved (capturing sunlight and converting this into marketable crops). Horticulture is important to the UK economy because of its productivity rather than its size. It also makes an important contribution to diet and health e.g. vegetables in the onion family; including leeks can also help to lower high blood pressure, a factor that can contribute to

6 NFU Why Horticulture Matters.

heart attacks and strokes.[7] Also research shows that eating cauliflower and broccoli twice a week can virtually halve a man's chances of developing prostate cancer.[8]

The UK fresh vegetable market is highly competitive, with constant price pressure on suppliers and producers. '*Every 10 years the number of leading packers in the UK is halved and the recession has made it an even more consolidated sector*.'[9] My own company (*Produce World Ltd; www.produceworld.co.uk*) competes with commoditised suppliers. The number of these has reduced from 37 to 20 in the last 15 years. This competition and associated profit margin squeeze contributes to a market failure situation where investment in research is needed to support innovation.[10]

The horticultural sector is characterised by high input, high output production systems. With the notable exception of carrots, vegetable crops are nitrogen demanding. They also require high inputs of plant protection products in order to meet the market demands for quality, notably aesthetic appearance. Anecdotally this demand can account for up to 80% of pesticides applied. The sector currently faces some of its biggest challenges to date concerning these inputs. I will now present the key drivers for lowering inputs and for my study.

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7 www.onions.org.uk (British Onion Growers Association)

8 BBC News; www.news.bbc.co.uk; Thursday 2 April 2007

9 Giles, J. Director Promar, Fresh Produce Journal 2010

10 Radcliffe, R. (2005). Review of the Agricultural and Horticultural Levy Bodies (Quinquennial review).

3. Drivers for lowering inputs

3.1. Legislative Drivers

3.1.1. Consumer attitudes

Consumer concern about the use of agrochemical sprays and fertilisers as a food safety concern is widespread[11] (34% of organic consumers surveyed gave the restricted use of pesticides as their top reason for buying organic).[12] Supported by influential lobby groups this has caused a policy shift towards risk aversion and environmental protection. Within the EU this is largely led by Scandinavian countries (particularly Sweden) and also the Greens (particularly influential in Germany). The net result has been a suite of EU Directives, creating tensions between food production and environmental protection.

3.1.2. EU Legislation

EU Directives are already impacting our access to crop protection products which have allowed us to produce affordable food (vegetables) reliably. The UK Chemicals Regulation Directorate (CRD formally PSD) recently produced an impact assessment stating that up to 50% production losses could occur as a direct result of this legislation.[13]

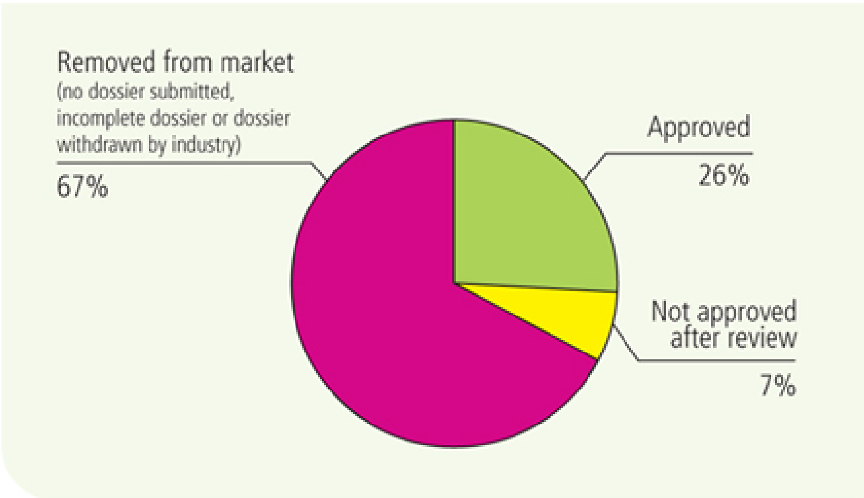

Fig.3. Impact of EU Directive 91/414/EC on availability of plant protection products

11 http://www.food.gov.uk/science/socsci/surveys/publictrackingsurvey

12 Soil Association. Organic Market Report 2010, p8.

13 CRD/PSD Summary Impact Assessment (Jan 2009)

Under EU Directive 91/414/EC, 74% of active ingredients have already been lost from the market (Fig 3). For example, there are 14% fewer Brassica insecticide approvals in 2010 than 2005.

Multinational agrochemical companies are not defending existing pesticides approvals and also not developing new products and technology for speciality ('minor') crops due to the massive investment required for development and registration (£250m. per active ingredient).[14] The irony is that the most nutritious food crops for which we need to encourage consumption will become more expensive and less accessible than ever as we see increased costs e.g. hand weeding and higher wastage due to pest and disease damage and crop losses. I saw evidence of this in Norway and Sweden where conventional carrot growers are now doing more hand weeding than before due to recent herbicide withdrawals including Linuron. In addition to this other EU Directives[15] are starting to impact the sector with respect to fertiliser use and particularly run off into watercourses (soils, fertilisers and pesticides).

3.1.3. Customer / retailer pressure

Four of the UK's leading supermarkets have their own particular requirements concerning the use of pesticides by their suppliers and have produced lists of restricted and banned products (over and above EU and national regulations). Some have gone further still by encouraging extended harvest intervals with the specific aim of reducing the incidence of pesticide residues in fresh produce. The danger of this strategy is that it could encourage greater use of less effective products and potentially build up insecticide, fungicide and herbicide resistance.

3.2 - see overleaf

14 Crop Protection Association Member, personal communication.

15 Soils Directive, Water Framework Directive

3.2. Economic Drivers

Fertiliser production requires high energy inputs and consequently price is closely linked to energy prices. The result is that the cost of fertiliser inputs is very volatile and increasingly expensive. The costs of nitrogen, phosphorus and potassium have risen by 45%, 79% and 68% respectively since 2003. The graph below (Fig.4.) demonstrates the volatility of the fertiliser market with 200% price rises from 2006 up to 2007/8.

Fig.4. Fertiliser price index (data compiled from World Bank Commodity Price Data)

Using a pesticide example; the Brassica industry standard module treatment, Dursban (chlorpyrifos) will be withdrawn December 2011 (SOLA 1390/2003). The new alternative treatment Tracer (Spinosad) is over 30 times more expensive to use (in house data, 2010), due to higher development and registration costs.

Clearly all inputs into vegetable production (with the exception of sunlight, air temperature and rain) cost money and price pressure on this relatively unsupported sector is massive, particularly since the recession. During this period the largest retailers have gone head to head in price wars and the internet has helped consumers to focus on price comparisons. As Rob Seeley (HSBC) said at our Nuffield Contemporary Scholars Conference, '*we need to focus on cost of production rather than price.*' So in essence we need to grow more with less. This is easier said than done but I am convinced that with science and collaboration on our side we can make some good progress towards this goal. Alex Evans puts it well when he states; '*a 21st Century green revolution is needed – one that not only increases yields, but that also moves from an agricultural model that is input intensive (in water, fertiliser, pesticides and energy) to one that is knowledge intensive*'[16] and science generates this knowledge.

16 Evans, A. (2009). The Feeding of the Nine Billion. Chatham House Report.

Different countries are experiencing different drivers to different degrees but, as many of our vegetables are now commodities, we are all facing similar economic and technical challenges.

This is why I was keen to learn how growers and researchers overseas were meeting the challenges to reduce their inputs and growing more for less, whilst maintaining high quality.

4. Definition

Low input: One of my first questions was : which inputs to study and what definition of low input to use. For example in an organic scenario we may use low inputs of plant protection products but have higher energy inputs (e.g. use of insect mesh covers for pest control and LPG for thermal weed control).

For the purposes of my study my definition is : vegetable production systems using low inputs of fossil fuel-derived or energy-intensive inputs, namely synthetic pesticides and fertilisers. Clearly other inputs must be considered but were not my principal focus due to limited time and resources.

5. Countries visited and their key concerns

During my study I discovered that legislative and commercial regulation of inputs was driving both adaptation and technology by growers, and research work. Early research led me to decide to visit: Scandinavia, the Netherlands, Belgium, California, New Zealand, Australia and Taiwan.

In **Scandinavia** environmental protection is key and legislation reflects this. Pesticide regulations are the strictest in the EU, as is legislation determining the amount of fertilisers used. In Sweden this is a direct result of pollution from crop production areas into the Baltic Sea and, in Denmark, diffuse pollution concerns have resulted in legal restrictions on whole farm fertiliser use (restricted to 90% of crop requirements).

I chose to visit **Australia and New Zealand** where the key driver to reduce inputs is economic and the aim is to achieve lower costs of production in order to export and compete in the global market. For example; onions can be transported from the Netherlands to Asia for half the cost of transporting onions from New Zealand to Asia (Mike Blake, *pers.comm*).

I also chose the **United States of America,** characterised by a high-input extensive production base where environmental drivers competed with food safety concerns and food safety is given priority.

Finally I chose **Taiwan** with its small scale highly intensive production systems, with a low emphasis on food safety and environmental concerns.

I also made a brief visit to the **Netherlands and Belgium** who face similar challenges to the UK. I selected countries with broadly similar climates to us purely to keep the findings as relevant to the UK as possible. Due to work commitments I had to travel over the winter period.

The challenges faced and potential solutions are summarised under five key headings:

Crop protection

Engineering

Weed management

Agronomy

Genetics

6. Key Findings

6.1. Crop protection Solutions

6.1.1. Biological products

Bio pesticides, also known as biological pesticides, are certain types of pesticides derived from natural materials such as animals, plants, fungi and bacteria. Bio pesticides fall into three major categories:

(1) Microbial pesticides,
(2) Plant-pesticides, &
(3) Biochemical pesticides

In California I met two development companies (Agraquest and Marrone Bioinnovations) who are both actively screening 1,000s of natural products to find new bio-pesticides to help plug some of the gaps left by the losses in conventional chemistry. Over 10,000 products have been tested so far. AgraQuest focuses on discovering, developing, manufacturing and marketing highly effective biopesticides and low-chemical pest and disease control, and yield enhancing products for sustainable agriculture. I was encouraged that so much activity is going into developing synthetic pesticide alternatives, and it is very telling that the multinationals such as Bayer, Syngenta and Monsanto are all actively engaged in this growing sector. For example, Monsanto have recently entered collaboration with Agraquest to develop novel seed treatments.[17]

Fig.5. Screening for new biological plant protection products

17 http:/www.agraquest.com

Some example products with US registration with potential for UK vegetable use are listed below:-

Requium targets; sucking pests; thrips, whitefly and aphids (active from egg to adult). With a 0 day pre-harvest interval (PHI), it is reported to have negligible to zero impact on beneficial insects. Its modes of action are:

- breaks down insects' exoskeleton,
- clogs insects' airways / breathing tubes
- and disrupts insects' navigation

– approvals include; Brassicas, bulb vegetables, leafy vegetable. The active ingredient is *Chenopodium ambrosioides*. Further details including label, approved crops and compatibility can be found at http://www.agraquest.com/agrochemical/products/insecticides-requiem.php

Serenade and **Regalia** are both active against *Botrytis* species and *Fusarium* species. Their modes of action are to trigger plant defence response producing anti microbial and anti fungal compounds, and also plant antibodies called phytoalexins. Regalia, based on extract of giant knotweed has shown useful efficacy in tank mixes for the control of downy mildew in head lettuce.

For further details please go to:

http://www.agraquest.com/agrochemical/products/fungicides-serenade-max.php (for Serenade) and http://marronebioinnovations.com/products/RegaliaSC/ (for Regalia).

In Davis, California, I met serial entrepreneur Pam Marrone, whose third company (Marrone Bioinnovations) is rapidly screening naturally derived products for crop protection activity. Some of these products are listed in the weed management section later. The bio pesticide product developments include a new bacterial based insecticide (the first since *Bacillus thuringiensis*), which has activity against caterpillar pests, including Diamond Back Moth. I was told that a biological alternative to Glyphosate should be available within the next two years! This is a bacterial-produced product with systemic activity.

There are also armies of students in Christchurch, New Zealand, who are discovering and developing crop protection products from naturally occurring plant, soil, fungal and bacterial sources. I have recommended to my sponsors Horticultural Development Council (HDC) that these products are included in their current and future R&D projects, including the SEPTRE LINK project.[18] In addition I have recommended to them that all crop protection proposals include a pesticide-free component (with a full cost benefit analysis). HDC Research recommendations are presented in Annex 1. The main barrier to entry for UK growers will be registration, as bio pesticide products tend to have a

18 Sceptre LINK project

narrow target pest or disease range, and thus a small market potential, coupled with relatively high registration costs. The UK government needs to facilitate a streamlined registration system to enable these products, with proportionate safety considerations, to reach the UK market. Previous attempts to introduce more bio pesticides have not resulted in many new products reaching the UK market due to prohibitively high cost of registration and limited market potential.

Research projects also need to investigate these products in a new way and not focus on a direct comparison with existing synthetic chemistry as it is likely that these new bio pesticides will be less persistent than synthetics and may need to be used in mixtures. Independent data on effectiveness is needed, particularly given the number of 'snake oils' pedalled to UK growers with unsubstantiated claims about their effectiveness. Knowing a product does not work is as valuable as knowing that a product does work, as it allows us to focus development in the right areas and save money on ineffective treatments.

6.1.2. Attention to Detail

Cultural / Integrated Pest Management approaches to crop protection have a role to play as we have learnt with our own organic production experience. Crop scouting is not rocket science, but as fewer people farm larger areas the need for this becomes even more important. It all comes back to attention to detail (Fig. 5 is an example), but better organisation and new technologies can also help here.

Fig.6. Using blue sticky traps in Brussels sprouts for pest monitoring

The use of sentinel plants is only at a concept stage (in protected crops) but hopefully may in future offer more intelligent agronomy to UK vegetable growers and should be part of the strategic research programme, not only to indicate plant stress due to pest and disease attack but also by extending this use to water and nutrient stress monitoring.

The Norwegians are using insecticide-impregnated mesh fences (with Deltamethrin) as a barrier and control for vegetable fly pests (cabbage root fly and carrot fly). Whilst the Norwegians are happy with the technology which is approved and commercially available, I cannot see the UK health and safety and pesticide regulators allowing it here. Its mode of action is indiscriminate so will also 'control' beneficial insects.

6.1.3. Integrated Pest Management (IPM)

IPM, including biological control, has been around for a long time in protected cropping, but has not been fully exploited in field vegetable production. I met Australian entomologists who are educating supermarkets on crop quality assurance relating to pest incidence. They have successfully changed field practice with respect to insecticide selection and in one case have allowed insecticide-free vegetables to be produced without covers in some seasons.

A level of education is needed to focus the quality assessor on the 'glamour' of the vegetable first and only then to assess the presence of pest or beneficial insect. Clearly entomology support and training are key to giving us confidence to hold back from applying a control treatment and to let nature (beneficial insects) do their work (biological pest control).

Two quotes I took from an IPM specialist in Australia:

> '*most problems come from bad spraying*' and
>
> '*spraying has become a bit of a habit.*'[19]

Product knowledge, weather conditions, time of day, pH and application type, all affect pesticide performance. For example; Tracer and Dipel are both broken down by ultra violet (UV) light, so should be applied late in the day. My challenge to my sector would be to ask, do we know enough about the products we are applying?

A key driver to increase IPM uptake in Australia was the development of Pyrethroid resistance in vegetable insect pests. Researchers and extension workers have summarised 20 years of R&D into a single publication (which I have forwarded to my sponsors)[20] Tracer and Pyrethrum (both organically approved insecticides) kill *Aphidius*, a beneficial insect aphid parasitoid which naturally regulates aphid populations and therefore needs protecting. Guidelines are given to ensure that use of broad spectrum materials is towards the end of the crop production cycle to minimise any detrimental effects on beneficial insects.

19 Jessica IPM expert, Victoria, Australia (*pers.comm.*)

20 New Zealand Brassica IPM manual. Hort. New Zealand

Another example of integrated control of insects was the use of manures to encourage soil dwelling mites which in turn attacked the soil phase of insect pests and offered a degree of control. Unfortunately food safety concerns would not allow this technique in UK fresh vegetable production; however heat treated or composted manures warrant further investigation / research.

Surely the most unusual example of biological control which I was introduced to during my study (Fig.7.) was the preying mantis! It was being used in an organic orchard for general pest management – although this will have limited uptake in UK temperate conditions.

Fig.7. Biological control in Taiwanese organic pip fruit orchards

6.1.4. Companion Planting

Companion planting: in the United States a plant called *Alyssum* (Fig.8.) is used to encourage natural enemies (particularly hoverflies) into the cropped area, providing natural control of crop pests. This has had particularly good uptake for leaf miner management.

Fig.8. Alyssum on an organic vegetable farm, California

In New Zealand they are also using buckwheat for the same purpose of companion planting (Fig.9). Buckwheat also produces and releases an enzyme which makes phosphorus (P) ten times more available to the crop than normal. This could have a role in soils with high P indices where P is believed to be locked up. These companion plants should be tested in the UK to evaluate what they can contribute and how to optimise their use.

see picture of buckwheat overleaf

Fig.9. Buckwheat in flower

In Holland and Belgium annual flowering field margins have been investigated to encourage and enhance levels of beneficial insects, which in turn help to control pest insects in adjacent crops. This benefit was demonstrated for potatoes and wheat crops; however the research on Brussels sprouts was inconclusive due to the complex of different pest insects involved (including whitefly, cabbage root fly, peach potato aphid, cabbage aphid, thrips and various caterpillar pests).

Work in Sweden is complimenting UK science in this area identifying the optimum plant species mixture to provide food sources (nectar and pollen) for beneficial insects and will include evaluating effects on neighbouring Brassica crops.

Some growers have planted sacrificial crops two weeks ahead in order to encourage the introduction of beneficial insects (e.g. rocket). Others in Wereby, Australia, are planting cereal margins to encourage aphid and their parasitoids into the vegetable field area, which can act as a ‘bank’ for biological pest control.

The New Zealand potato industry is currently under siege: crops are being written off due to a new *Psyllid* pest (Fig.’s 10 & 11). Practically all the entomologists in the country are working to find a solution, but so far nothing is in place. Whilst this problem is not present in Europe or Australia, it is a sobering reminder that we need to keep a few insecticides in the armoury if only as an insurance policy against this type of unfortunate occurrence. The relatively recent arrival of tomato pest *Tuta absoluta* to Northern Europe including the UK is another reminder of the potential dangers of pest migration either through climate change or 'leaky' border control.

Fig.10. Potato *Psyllid* adult (left) and Fig.11. Tuber symptoms known as zebra chip disease (right)

7.1. Engineering Solutions

7.1.1. Precision Agriculture

Precision agriculture is becoming well developed in the USA although uptake is still only around 3% of farms. It has now been exported well to the southern hemisphere thanks largely to a couple of Nuffield scholars!

Areas for us to seriously consider are:

soil mapping for vegetable cropping

electromagnetic induction (EMI) and electrical conductivity (EC),

on the go soil moisture

compaction monitoring

yield mapping, which has some way to go in the vegetable sector where crops like Brassicas (hand harvested) are more difficult to record than wheat using combine yield maps.

Controlled traffic farming is another area with good potential to reduce fuel costs through reduced tillage, which is just starting to be explored now in the UK (vegetable sector).

An area of particular interest was the use of strip tillage. One grower halved his diesel consumption by adopting this system, at the same time speeding up work rate and improving soil structure. Whilst vegetable crops require close spacing I believe that there is a role for this system in transplanted crops down to 14 inch spacing, although it may take a few seasons to realise the soil structural benefits. No till systems have been trialled for potatoes and transplanted crops (USA) and drilled crops (Holland), but results on drilled crops were poor.

Another example of an engineering solution is the Weed Seeker, which uses a light emitting diode (LED) source to transmit towards the ground. This light is reflected back, detected by the machine and results in a spot spray treatment only where weeds are present. It is used in US and Australia in row crops, operating using a hood system like the Micron sprayer (Vegedome). Whilst UK research project is developing a more sophisticated system, this system is off the shelf and available today.

I was also particularly interested in the Green Seeker, an on-the-go canopy sensor system using normalised difference vegetative index (canopy greenness), and being used to apply variable rate fertiliser.[21] This technique is also used from planes and the information used to apply plant growth regulators to cotton crops. This needs developing for most vegetable crops which are nitrogen responsive (e.g. brassicas, onions and leeks). It has already been developed for potatoes, although correlating above ground to below ground performance is very difficult.

We need to know first, though, the levels of variability in our crops (range) to decide if they are sufficiently high to warrant a precision farming approach. It was suggested to me that it will only work if we have a high enough level of variability (circa. 40-50%). However, with the volatile and rising cost of fertiliser inputs this should be investigated (feasibility study) as an option to reduce these inputs even if it is not cost effective using October 2010 fertiliser prices.

21 http://www.ntechindustries.com/greenseeker-home.html

7.1.2. Engineering Solutions to Disease Control

In Sweden I saw a UV field machine (Fig.12.) for controlling disease in *Allium* crops (under development).

Fig.12. UV treatment rig – development trial 2010

This works on the concept that wavelengths in the UV range can be used for sterilisation (e.g. water treatment, food industry; juices etc). Direct exposure to UV (sunlight) is known to reduce disease levels. UV machines are already used in protected cucumber crops for disease management. The issue is to achieve a uniform treatment exposure with a crop like onion where the leaves are rounded (cross section) and overlap significantly. Also repeat treatments would be needed to achieve control throughout the season particularly during periods of rapid leaf growth. Another constraint is that UV tubes are delicate and would need robust protection in a field vegetable crop which will reduce efficiency. There is definitely scope for further evaluation and development of this technique.

8.1. Weed management solutions

8.1.1. Organic learnings

Learning from organic systems informs conventional systems and vice versa. Irrigation is being used successfully by Australia's leading organic vegetable growers (in Tasmania, Australia) to manage weeds (to trigger flushes which are then controlled using thermal treatments) and pests (where it is used to stimulate biological fungal control through high humidity – on an organic farm near Napier, New Zealand).

Whilst our own natural rainfall is impossible to predict there are ideas which could be developed in a UK context particularly as water availability creeps up companies' agendas. In the USA I found non-synthetic, organically approved herbicides which I believe need developing for the UK market. For example Green Match is an organic herbicide that controls a broad spectrum of annual and perennial weeds, both grasses and broadleaves. The active ingredient in Green Match is d-limonene, a citrus oil extract and powerful natural degreasing agent that strips away the waxy cuticle from leaves, causing rapid wilting, dehydration and death. There are also two vinegar-based products also contact acting and others based on plant oils. The best non-selective treatments were Matran (clove leaf oil) and a 50% clove oil mixture with 50% cinnamon oil (WeedZap).

See US trial result photos for these two treatments in Fig.13 & 14 (next page) where all treated weeds were controlled.

Fig.13. Matran 15% + 0.05% Natural Wet @ 70 gallons per acre

Fig.14. WeedZap 10% + 0.05% Natural Wet @ 70 gallons per acre

There are comprehensive trials which are available on request, which I have sent to my sponsors in the hope that they will include some in 2011/12 UK trials. In New Zealand they also tested a pine needle extract, which showed efficacy (contact action). A new pipeline product from Marrone Bioinnovations is mentioned earlier, but also warrants investigation for UK use and registration.

Interestingly in Sweden where they have already banned Linuron (a key herbicide for carrot production) and Ioxynil (Totril) they had no alternative solutions and were forced to use hand labour in conventional crops (which is very expensive). They are now getting problems with both volunteer potatoes and black nightshade. This is ironic considering it is Sweden in particular who are driving to eliminate pesticide use. We have a high input production system based on 30 years of research; now that we are changing direction to lowering such inputs we need equivalent research effort to achieve our objectives and continue to grow affordable vegetable crops.

9.1. Agronomy solutions

9.1.1. Catch and cover crops

In Scandinavia I saw some new research investigating the potential of cover and break crops to scavenge and mine for nutrients down the soil profile bringing them up to the top layers. This way nutrient leaching to watercourses was reduced and the potential to reduce fertiliser inputs introduced.

I think that for too long in conventional vegetable production we have focused on the crop above ground at the expense of our plants' roots systems and soils. Did you know that carrots can root up to a depth of 1.2 metres and Brassicas to over 2 metres? The Scandinavians are focusing on roots – thinking of the soil as 3D instead of 2D (Fig.'s 15 & 16).

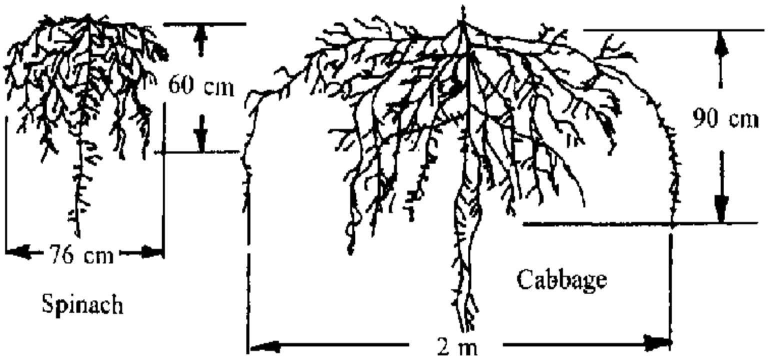

Fig.15. Carrot roots (left) and Fig.16. Cabbage roots (schematic - right)

This understanding of the root systems should have a bearing on our soil and nutrient management decisions and also our crop breeding. New and existing plant species are being investigated to give us more options to mine and catch nutrients and to improve our soil quality. Rotational cover crop research trials are investigating the potential of new species to capture nutrients and include Dyer's Woad *Isatis tinctoria* (pictured in Fig.17, see overleaf) which will accumulate phosphorus levels of 0.45-0.59% within the plant leaves. The chemical composition is affected by plant age, the optimum timing being usually before flowering.

Other examples under investigation include garden sorrel (accumulates K), fodder radish (accumulates S) and ryegrass (accumulates N). In a rotation of rye, cabbage or lettuce, oats, onion plus intercrops and cover crops, nutrient leaching was reduced by 20-30%.[22] Cover crops are now compulsory in Denmark, covering 10% of farmed area. Growers have had to adapt to this for spring drilled and spring planted vegetables.

22 Prof. Kristian Thorup Kristiansen (*pers.comm.*)

Fig.17. Dyer’s Woad (used as cover crop)

9.1.2. Green manures

Green manures are well investigated in the UK and particularly in organic systems. The University of California Davis experimental farm, Russell Ranch, has a long term trial (year 16 of a 100 year trial) investigating low tillage systems, organic, low input, conventional and green manure cover crop (vetches), all aiming to achieve optimum use of inputs. They presented a balanced view of each option, e.g. low till results in higher soil organic matter but can reduce nutrient cycling; also green manures fix atmospheric nitrogen, but can increase green house gas emissions.

Fig.18. Russell Ranch Long Term Rotational Trials

A current ADAS study is attempting to put a value on green manure crops in terms of nitrogen fixed and converting to nitrogen fertiliser equivalent, which should help to generate cost benefit information. This could provide a business case for the use of green manures. Recent HDC fact sheets summarise UK research to date, but more research is now needed particularly regarding quantifying the benefits of the shorter term break crops and intercrops which could fit our current short term rent production model (where a large proportion of UK vegetables are grown on rented land).

9.1.3. Soil health and protection

The condition and health of our soils fundamentally affect a plant's ability to feed and drink and maintain a high health status. For example, biologically active soils cycle nutrients more than poorer soils, allowing fewer nutrients to be applied. Clearly this contribution to nutrient availability needs careful monitoring to provide sufficient confidence to apply fewer nutrients than normal. Healthy crops are more resilient to pest and disease attack than stressed crops. Soils are a finite resource and need protection from wind and water erosion. Soil health and protection are vital to the long term sustainability of our UK vegetable production base. Organic matter is known to be linked to soil health and experiments in the USA have demonstrated that concentrations can be increased by up to 8% in only 4 years. Organic matter also improves soil structure which will help mitigate soil capping and soil erosion. Whilst a number of case studies and knowledge transfer activities have been completed there is still scope for more demonstration sites to encourage a more strategic management of our soils.

9.1.4. Soils and controlled traffic

During the study I met a number of converts to Controlled Traffic Farming (CTF) at both grower and experimental scale. This system uses global positioning system (GPS) to position and maintain wheelings in the same place year on year, reducing soil compaction and improving soil structure and performance. The issue for the UK vegetable grower base, is the high proportion of rented land and investment required (compatibility of equipment). Further development of seasonal controlled traffic may be an option and is something UK vegetable growers should consider. In Tasmanian experiments potato yields were greater under CTF compared to normal traffic system. Development of systems for other vegetable crops is now underway in Europe.[23]

9.1.5. Rotations

It almost goes without saying that good rotations will help nutrient budgeting and have the potential to reduce fertiliser inputs, particularly when cover crops and green manures are included. Again at the risk of stating the obvious, much can be done to manage issues before the crop is ever drilled or planted; a useful reminder from our organic experience. Volunteer potato control in vegetable crops is a good example of this, where volunteers should be managed elsewhere in the rotation (i.e. before the onions, leeks, peas, carrots or parsnips are drilled). Bio fumigant crops (tested everywhere I visited) can be used to reduce soil borne pests and diseases but I have learnt that the management of these (relatively expensive) crops is key (timing and incorporation) in order to achieve an acceptable result. I am still a little sceptical about how effective they are and I am still waiting to be convinced. Numerous studies from Denmark and Holland were inconclusive in demonstrating benefits from bio fumigant crops.

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23 Tim Chamen CTF Europe, pers.com

10.1. Genetic solutions

10.1.1. Good genetics

These are foundational to crop success and in Taiwan, Australia, NZ and the EU I found that genetic material is available (though not always immediately) and will provide some of the solutions we need. In Taiwan there are 57,175 different vegetable crop species stored, a fantastic genetic resource, linked to numerous other international gene banks. Of the world's 27,000 edible plant species less than 50 species account for 90% of global sales.

At the World Vegetable Centre the focus is on the nutrient value of vegetables, addressing environmental stresses such as drought tolerance and encouraging the use of locally adapted varieties (land races). Their aim is to help to eradicate global poverty but they are also focusing on countries where over-eating is causing health issues.
Two vegetable examples are slippery cabbage (a healthy and resilient indigenous variety) and bitter gourd (which can help to reduce blood glucose).

Advances in gene marker technology will help us to capture the power of plants to defend themselves from pests and diseases, make more efficient use of nutrients and potentially expand production areas to less favourable growing areas. Also international plant breeders and researchers are focusing on nutrient enhanced lines to improve the nutritional content of key vegetables e.g. Booster broccoli (with enhanced glucosinolates) and ACE peppers (with enhanced vitamin A, C and E). Genetics are fundamental to delivering more food to feed a growing population.

The theoretical yields in the UK environment, assuming that future research enables all physiological targets to be met, have been estimated to be 19.2 tonnes per hectare for wheat (Sylvester-Bradley et al, 2005), with a realistic yield potential 11.4 t ha.[24] Equivalent data are not available for vegetables, but we should be able to assume that vegetables can realise similar potentials.

One of my key recommendations is that plant breeders begin to select vegetable lines under sub-optimal input conditions e.g. water stress (for drought tolerance), saline water and heat tolerance. This will provide us with the back bone of our low input systems in the medium to long term. Among the breeders I have spoken to, this is not a major focus for them, but this needs to change.

24 http://berr.gov.uk/go-science/science-in-government/key-issues/food/~/media/5C4E476342334B608B748767805B1115.ashx.

10.1.2. Role of Genetically Modified Organisms (GMOs)

Surely genetic modification will solve all our problems: nitrogen fixing vegetables to reduce fertiliser inputs and reduce nutrient leaching, pest and disease.

Whilst I did not study genetic modification specifically, this is clearly a breeding technique which could deliver significant advances. However, as with all technologies it needs to be used in an integrated manner (it is not the silver bullet, as it is often presented, rather part of the tool kit). I deliberately chose not to study GMOs (a study in itself) principally on the grounds of needing to focus my study and wanting to make it relevant to UK farming over the next 10 years. The UK vegetable supply chain is short and therefore highly scrutinised and influenced by public opinion and I do not believe that our market will receive genetically modified crops over this timeframe.

It is true that this new technology can accelerate conventional plant breeding, although non-GM techniques are already helping us to achieve some of these objectives through the use of marker assisted breeding and gene sequencing. e.g. extra rooting Brassica varieties for clubroot tolerance and downy mildew resistant onions (both now grown commercially in the UK).

It is interesting that one of Europe's leading independent vegetable seed houses has taken a non-GM stance, which I believe reflects our current market position.

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11. Conclusions and Recommendations

This study has demonstrated clearly to me that the drivers for low input / impact production systems are here to stay, and affect different countries to different extents. Environmental protection is an international concern, and particularly so within the EU. Economic pressures in our competitive market place will only heighten. Therefore as researchers and growers we have to learn to adapt and innovate. However, specific technologies are available while others need further development and road testing in the UK.

The study has demonstrated to me that we *can* deliver the tools needed to produce enough quality food within environmental constraints. I have summarised my conclusions and recommendations below:-

11.1. Key Inputs

- **Biological controls need developing for outdoor field crops**, and companies are only just beginning to address this need. It is encouraging to witness these developments but more is needed to plug the gaps left by the loss of synthetic pesticides and further research to learn how to get the best out of these products / tools.

11.2. Integrating inputs

- Internationally there is a huge resource of research knowledge into integrated pest management systems, including the use of naturally derived products. This also becomes a bit of a minefield given the number of 'snake oils' being touted. For this reason **there needs to be independent screening under UK conditions, accepting that we will not be able to directly compare with synthetic chemistry.**

- Natural enemies have a lot to offer us as vegetable producers, and careful monitoring can allow us to reduce insecticide inputs. However, **there is an education job to be done with both our customers and consumers regarding how quality is measured and valued.**

11.3. Optimising inputs

- We have an unprecedented opportunity to marry new information technology which can handle large amounts of data with an understanding of our key production inputs to gain a better understanding of our production systems (e.g. crop variability), farm more efficiently, improve quality, plan better and reduce crop wastage. This is particularly important where farms have expanded/ consolidated and specialist and local knowledge is not always available, particularly where rented land is used for vegetable growing (which is commonplace). **Information technology informing intelligent agronomy will help**, but there remains a place for scrutiny and **attention to detail** even as these **new tools** emerge.

11.4. Recapturing inputs

- Visiting Scandinavia has convinced me that we need to **pay more attention to crops below ground**, particularly in high quality vegetables where crop uniformity is paramount to reducing wastage and expensive fertiliser inputs. There is an obvious need here for some **technology transfer work**. In addition there is scope for **further evaluation and adoption of fertiliser placement options**.

- Whilst organics are a small part of our production base and will continue to be so, every vegetable grower I have spoken to has learnt something from trying organic production. My recommendation is that **more research should take place in organic systems**, which will offer benefits to conventional growers in the areas of **nutrient, soil and water management** and in addition **crop protection approaches**.

- We need to **revisit some 'ancient wisdom' regarding our soils** and how they are managed and treated. The way our vegetable industry and supply chain has evolved over the last 20-30 years has been to the detriment of our soils, which are some of the best in the world, a precious and finite resource. **Research** is beginning again, and will help to deliver cost effective options **to enable us to improve and manage our soils.**

- Genetics is the fundamental tool to deliver these changes and is already coming on stream. However, plant breeders and researchers need to **investigate plant breeding under sub optimal conditions** (e.g. drought tolerance and tolerance to more saline water), to deliver the key input required for a low input production system.

11.5. Sharing Knowledge through Collaboration

- Finally a key recommendation of my study is that there is a vast amount of common ground (technical challenges) facing vegetable growers and suppliers. **Greater international scientific collaboration** (more efficient use of resources and knowledge and experience) **and knowledge transfer to UK vegetable growers** are essential to enable us to continue to grow and develop our businesses.

- There is a particular need now for **research, development and 'road testing' or demonstration work in the UK** to make the most of these ideas. As a result of this study I will be presenting a list of horticultural research needs (for vegetable growing) to DEFRA, BBSRC, AHDB and UK retailers in addition to working within my own business. These are listed in Annex 1.

These conclusions can also be summarised under four headings;

- attention to detail
- application of science
- adaptation to change
- and ancient wisdom.

Delivery of these will take efforts from individual farm level up to government and policy level. particularly in respect to research to support development, knowledge transfer and innovation.

Finally, the most important thing for me and my business from the Scholarship and Nuffield experience has been;

- the international contacts I have made,
- the numerous ideas this has generated and the fresh thinking I have been exposed to, and the new perspective this has given me.

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Annex 1. HDC Recommended projects (presented to HDC Field Vegetable Panel in September 2010)

- Screening of biological crop protection products; SCEPTRE LINK project
- All crop protection proposals to include a pesticide-free component with costings
- Engineering options for crop protection – development trials
- IPM demonstration projects and training
- Soil health projects; root systems and rotations, catch and cover crops, controlled traffic farming in vegetable crops
- Incorporate nutritional value assessment into variety trialling
- Plant breeding / variety selection under sub-optimal conditions (e.g. moisture stress, salinity)
- On the go N sensors, calibrated for Brassicas, alliums, potatoes and salads
- Organic herbicides included in HDC herbicide screening projects

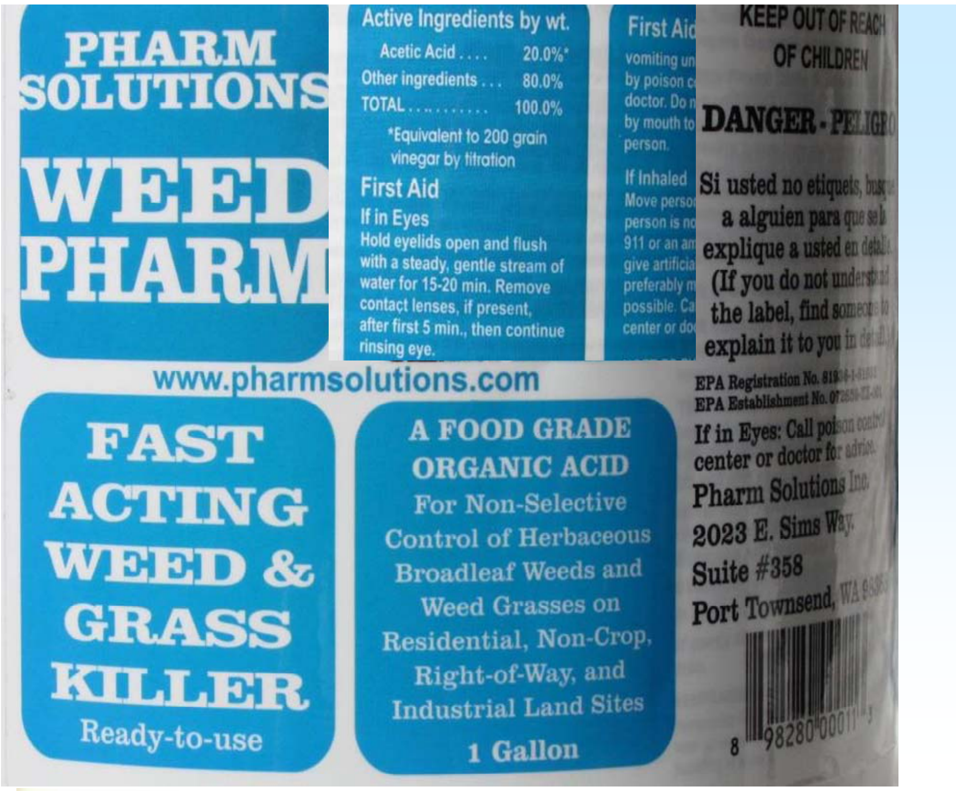
General Recommendations to HDC FV Panel and HDC Board (presented July 2010)

- More international collaboration; clear opportunities in USA, Australia, New Zealand
- EU level require collaboration at strategic level
- Knowledge Transfer information available e.g. New Zealand
- Encourage all vegetable growers to apply

Annex 2. DEFRA & BBSRC Recommended projects (to be presented in December 2010)

1. Plant breeding under sub-optimal conditions
2. Developing soil health indicators for UK soils (field scale)
3. Value of soil for carbon storage and water retention
4. Understanding variability and the potential of precision farming techniques for the vegetable sector
5. Remote and in field sensing technologies for assessing crop uniformity
6. Novel techniques for crop protection and nutrient delivery
7. Sentinel plants – Monitoring crops through use of indicator crop plants

Annex 3. Organic herbicide labels (USA approved)



OMRI

WEED ZAP™

A NON-SELECTIVE HERBICIDE FOR ANNUAL GRASSES AND WEEDS

JH

General Information

WEED ZAP is a contact, non-selective, broad spectrum, foliar-applied herbicide. This product will only control actively growing emerged green vegetation. It controls both annual and perennial broadleaf and grassy weeds. This product does not translocate. It will affect only those plants that are coated with the spray solution.

ACTIVE INGREDIENTS:

Clove Oil 45%
Cinnamon Oil..................................... 45%
Inert Ingredients: 10%
Lactose and Water.
TOTAL 100%

This product is exempt from registration with the Federal EPA under section 25 (b) of FIFRA. WEED ZAP has not been registered with the Environmental Protection Agency. JH Biotech, Inc. represents that this product qualifies for exemption from registration under the Federal Insecticide, Fungicide and Rodenticide Act.

International & United States Patents Pending

APPLICATION RATE TABLE

Mix 3 gallons of WEED ZAP concentrate per 100 gallons of spray water. Apply enough WEED ZAP to cover the entire surface of the weed. Spray to the point of run off. The use of a spreader/sticker such as JH Biotech's Natural Wet® may increase contact and efficacy of treatment.

FINAL MIX VOLUME	FL. OZ.
1 Gallon	4
5 Gallons	20
10 Gallons	40
25 Gallons	100

Repeat application as necessary. Coverage is essential to establish control.

Lot #:

CAUTION KEEP OUT OF REACH OF CHILDREN

PRECAUTIONARY STATEMENTS

Off target application of WEED ZAP will result in damage to growing plants. Do not apply this product through the irrigation system.

Avoid contact with skin, eyes or clothing. In case of contact, immediately flush eyes or skin with plenty of water. Get medical attention if irritation persists.

STATEMENT OF PRACTICAL TREATMENT	
IF SWALLOWED	-Call a Physician or Poison Control Center. -Drink one or two glasses of water. -Do not induce vomiting. -If person is unconscious, do not give anything by mouth or induce vomiting.
IF IN EYES	- Hold eyelids open and flush with a steady, gentle stream of water for 15 minutes. -Get medical attention if irritation persists.
IF ON SKIN	-Wash with plenty of soap and water. -Get medical attention if irritation persists.

LIMITED WARRANTY

Manufacturer or seller makes no warranty, whether expressed or implied, concerning the use of this product other than for the purposes indicated on the label. Neither manufacturer nor seller shall be liable for any injury or damage caused by this product due to misuse, mishandling or any application not specifically described on the label.

Manufactured By: JH Biotech, Inc. P.O. Box 3538 Ventura, CA 93006

NET CONTENTS:

- ☐ 1 Pint (0.47 liter)
- ☐ 2.5 Gallons (9.45 liters)
- ☐ 2 x 2.5 Gallons (18.9 liters)
- ☐ 5 Gallons (18.9 liters)
- ☐ 55 Gallons (207.9 liters)

Weight per Gallon: 8.4 lbs.

0216-D-A-1

JH Biotech Inc.