A Nuffield Farming Scholarships Trust Report

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AHDB Cereals and Oilseeds

The potential for companion cropping and intercropping on UK arable farms

Andrew Howard

July 2016

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A Nuffield (UK) Farming Scholarships Trust Report

Date of report: July 2016

"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	**The potential for companion cropping and intercropping on UK arable farms**
Scholar	Andrew Howard
Sponsor	AHDB Cereals and Oilseeds
Objectives of Study Tour	To discover the potential for companion cropping and intercropping utilisation on UK arable farms and to understand the benefits and limitations of such systems.
Countries Visited	France, USA, Canada, Germany, Switzerland, Kenya, South Africa, Sweden, Denmark and the UK
Messages	• Companion cropping and intercropping has the potential to produce up to 30% more crop yield while also allowing for a reduction of off-farm inputs • To achieve success you need good planning: it is a management and knowledge-intensive approach to farming • Every farm, soil type and climate will lend itself to different cropping combinations. There is no one blueprint that will suit everyone. • There are limited opportunities for patenting in intercropping so funding for research will be limited unless supplied by farmers, levy boards and governments. • Machinery design needs to improve and evolve to improve the practicalities of companion cropping and Intercropping • Intercropping is a must for a future regenerative agriculture!

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1. About me

I grew up on our family farm on the outskirts of Ashford, Kent. Both my parents are from farming families so I guess farming is in my blood, though I spent the first 22 years of my life convinced I wasn't going to be a farmer. While I was growing up my father farmed a multitude of crops and livestock from cereals, roots, vegetables to turkeys, sheep and beef cattle. After a summer working in a supermarket and dealing with the general public, I came to the conclusion that the lonely isolated life of a farmer may not be such a bad thing!

Figure 1: The author, Andy Howard

I studied Environmental Management at Durham University and after a year travelling the world I decided farming was for me, so I spent a year at The Royal Agricultural College to improve my knowledge of agriculture. Since I left the RAC (now RAU) in 2003, I have been full time on the farm working with my parents. When I returned home we were a mixture of arable and livestock including a beef suckler herd and sheep. After a few years I realised that I was not a stockman and so the livestock left and we now only farm combinable crops (winter wheat, winter barley, spring oats, winter and spring field beans, winter triticale and spring linseed). We also rent out land for a solar farm.

Since coming home to the farm I became more and more interested in soils and Regenerative Agriculture. Since 2002 we have had a progression from Min-till to Strip Till and now we are No-till. Looking after our soils is my number one farming priority. My interest in Regenerative Agriculture was sparked by reading a book by the Australian consultant Graeme Sait called "Nutrition Rules". In this book he interviews other consultants about how they farm with no, or lower, inputs by utilising nutrition, soil biology and other "out-there" ideas. The whole premise was that diseases, weeds and insect attacks are symptoms/indicators of your problems and to solve them you need to look at the root cause which is normally found in imbalances of soil health and nutrition. This book triggered me to research more into this subject and now I have a mini-library of similar volumes. For almost a decade I have been experimenting with methods of soil improvement and nutrient balance to help to improve our farm performance, with relative success.

In 2007 I met my partner Philippa and we now have 2 wonderful children. Rose is 4 and Charlie is 21 months. Charlie was born 2 days before my Nuffield Farming interview, so Philippa has been a single mum and Nuffield Farming widow since Charlie's arrival.

2. Why I applied for a Nuffield Farming Scholarship and where I travelled

Over the last few years I had looked into Nuffield Farming Scholarships but I had never taken it further, one of the reasons being that I did not know what I wanted to study. It was not until I was in a car with my friend Tom Sewell, a 2013 Scholar, that my interest was really triggered. Tom was at that time in the middle of his study tour and the idea of having travels around the world paid for and meeting the best farmers on the planet was strangely appealing! The previous year I had been to a meeting where a French farmer, Frederic Thomas, was speaking. He talked about No-till and cover crops and then at the end of his talk he spoke about companion cropping with oilseed rape. This seemed like a crazy idea but got me thinking. I went home and experimented on my own farm with oilseed rape companion cropping in 2012. After that I was hooked and I realised that I now had my subject for a Nuffield Farming Scholarship. So after speaking to my family I applied for one - and the rest is history: well, actually it's written below!

2.a. Where I travelled

I had a fair few trips in the UK which I fitted in around the busy times on the farm and also had five trips abroad:

May 2015	I had four days in France. I chose to visit France as their climate is fairly similar to our own and they were ahead of us in terms on companion cropping and intercropping research and on-farm practices.
June/July 2015	I spent 4 weeks in the USA and Canada. There were a number of very innovative farmers and researchers that I wanted to visit who were very relevant to my subject even though their climate is different
November 2015	I spent 10 days travelling from Germany to Switzerland and France. My research had shown there was a large number of interesting researchers and farmers in these areas and so I wanted to explore the nearby continent as their cropping systems are very similar to our own
January 2016	I spent 7 days traveling around Kenya with fellow scholar Gordon Whiteford and then we spent another 10 days traveling across South Africa. I chose to go to Africa, especially Kenya, to see how farmers produced crops when they have little or no access or cash for off-farm inputs. I was interested to see what innovative techniques they employed. I had also heard that South Africa had some of the most innovative biological farmers in the world. I felt I wanted to visit somewhere different.
June 2016	I spent three days in Sweden and two days in Denmark. I wanted to visit Scandinavia as they have strict environmental laws and are restricted in what they are allowed to apply to crops. I wanted to see how they coped with all their environmental regulation as I believe we will be under a similar system soon here in the UK. Also their climate is similar to the UK's.

3. Introduction to companion cropping and intercropping systems

When I applied for my Nuffield Farming Scholarship I had only really just heard of the term "companion cropping". When I started to research the subject I realised there were many related terms and systems that I wanted to explore as part of my project. From now on the general term I will use is "Intercropping" (IC). I think this is the most commonly used term and one that is easy to understand. The general definition for Intercropping I am going to use is:

> *"The growing of two or more crop species where part or all of their crop cycle overlaps temporally and/or spatially, where one or more of the component species is taken to harvest"*

This definition covers the many types of intercropping systems that I have encountered in my study.

The aim of this Nuffield Farming report is to give readers an introduction to intercropping, and some guidance on what to do and expect when intercropping. It is not to be read as definitive as there are no right or wrong answers. There are many possible crop combinations that are feasible and only a small percentage is mentioned below. My hope is that it will give farmers enough knowledge, confidence and ideas for them to then experiment on their own farms.

Please don't be put off by the size of the report! I hopefully have laid it out in logical sections so that people can pick and choose which parts they want to read and can also refer back to the report later on.

3.a. The History of Intercropping

"During the last 60-70 years of agricultural intensification in terms of plant breeding, mechanisation, fertiliser and pesticide use, intercropping has disappeared from many farming systems. In contrast with most agricultural systems, biomass productivity in natural ecosystems is achieved through a high genetic diversity of plants involving different complementary functional groups" (*Malezieux et al 2007*).

The above quote describes what has happened in Western agriculture and to some extent agriculture in developing countries. We now have a system where mono-cropping is the norm. A lot of farmers would not necessarily know what intercropping or companion cropping entails and think of it as new technology. This is definitely not the case: monocropping is the new kid on the block. Before the Green Revolution (roughly 1940s-1960s) intercropping in some form was widespread across the globe. I have taken a few facts from John Vandermeer's book "The Ecology of Intercropping":

- in 1923 57% of Ohio's soya bean acreage was intercropped with maize
- in 1972 98% of cowpeas in Africa were intercropped with maize
- in 1975 90% of beans in Columbia were intercropped.

The list could go on.

Actually intercropping is an ancient art. The best known combination is “The Three Sisters”, which was grown by Native Americans over 5000 years ago. This involved growing maize, beans and squash. The maize would quickly grow tall, allowing the beans to use its stalk as a trellis, while the squash remained at the base shading out weeds. In terms of the UK, “dredge corn” was grown until the 1950s, which was a mixture of oats and barley grown for animal feed.

There are many more examples but my point is: intercropping is nothing new. It is well known that ideas in agriculture go in circles, going in and out of fashion at different times, so why is there such an interest in intercropping again? To answer this we have to ask ourselves why previous generations intercropped? It was because they didn’t have the modern tools of developed agriculture such as pesticides and fertiliser. Intercropping allowed them to grow crops successfully without such inputs being available. This is also why intercropping is still more prevalent in developing countries as they do not have the access or cash to buy such inputs. The modern boom in chemical farming is coming to an end. Now that weed, insect and disease resistance is becoming more and more prevalent, intercropping is one tool that can help us grow bountiful crops with lower inputs.

Figure 2: Peola: an intercrop of spring peas and oilseed rape grown on our farm

3.b. Terminology. **Note: for ease of reference this Terminology is shown again in Appendix 1, page 86**

OVER-YIELDING: the amount a species yields when grown with other species compared to yield in a monoculture. Most common reason for over-yielding is when crop mixtures exhibit temporal complementarity. In Canada in conventional agriculture you got over-yielding 75% of the time in intercropping, and in organic it was 47% of the time.

Continued on next page

FACILITATION: the process in which two individual plants or two populations of plants interact in such a way that at least one exerts a positive effect on the other. Double facilitation is equivalent to mutualism. (*Vandermeer 1989*)

COMPLEMENTARITY: when species differences give rise to a better overall use of resources in intercrops than in separate sole crops (*Vandermeer 1989*)

The diagram below outlines some ways species can facilitate and complement each other:

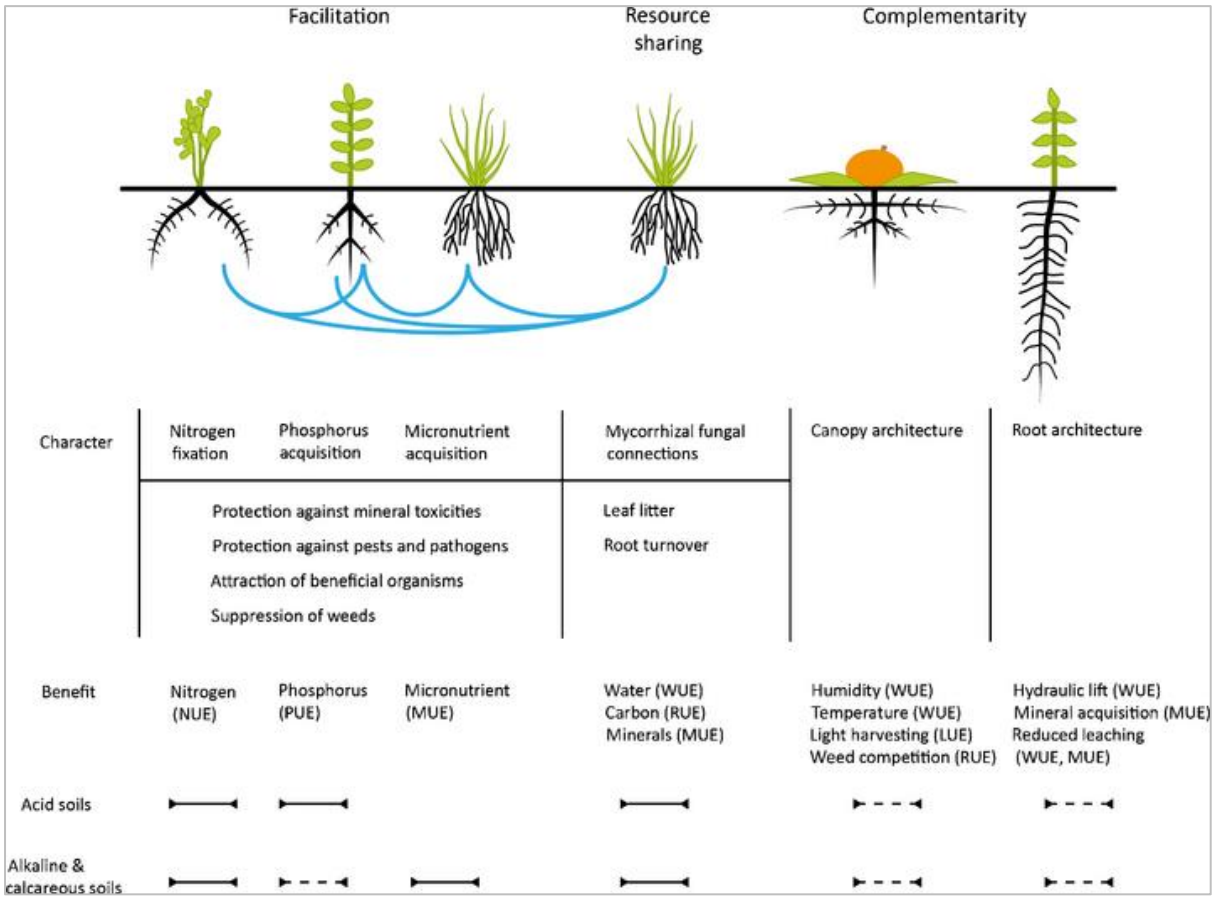

Figure 3: some ways species can facilitate and complement each other. (Courtesy of Brooker et al)

COMPETITION (INTERFERENCE): the process in which two individual plants or two populations of plants interact such that at least one exerts a negative effect on the other (*Vandermeer*). Competition is not as simple as described above; competition can lead to positive feedback if both crops are well established.

INTERSPECIFIC COMPETITION: the competition effect of one species on another species

INTRASPECIFIC COMPETITION: the competition effect of a species on plants of the same species

SPARING EFFECT: where legumes fix atmospheric nitrogen and so reduce competition for soil Nitrogen (N) with non-legumes

DILUTION EFFECT: an increase in biodiversity and species richness in a particular spatial locality is protective against disease/pest spread, due to less of the population being susceptible to the disease/pest compared to a population of genetically similar species - where all are susceptible.

PHYSICAL BARRIER EFFECT: a species of an intercrop creating an obstruction to a disease vector, pest or weed of the other intercrop component(s), so reducing/slowing down the spread of disease, pest or weed

THE CHEMICAL EFFECT: changes in the chemistry of the biosphere caused by a component of an intercrop to positively or negatively affect other species i.e. root exudates increasing nutrient availability or causing alleopathy.

ALLEOPATHY: alleopathic plants are species with the ability to produce chemical compounds which negatively influence the growth and development of weeds, pests or diseases (*Weston 1996*). Rye, sorghum and sunflower plants inhibit weed germination. Brassicas reduce weed germination, pests and diseases through the decomposition of their residues

REPLACEMENT AND ADDITIVE INTERCROP DESIGN: this is a question of plant population and seed rate. In a replacement design, mixtures are formed by replacing a given number of one component by the same number of the other component. As a result the relative density of each component is less than when grown in a pure stand, but the total stand density is the same. In additive design, mixtures are formed by adding plants of one component to the other component so the intercrop plant population density is higher than the monocrop.

3.b. Measuring and Modelling of intercropping performance

***Land Equivalent Ratio (LER) [or Relative yield Total (RYT)]*:** This is the most common measure of intercrop performance. It uses the following calculation to calculate how much land it would take to produce the same yield as the intercrop if the crops were grown as monoculture.

LER = Mixed yield 1/pure yield 1 +mixed yield 2/ pure yield 2

If the LER is greater than 1 then there is a yield advantage from the intercrop over two separate monocultures. If the LER is greater than 1 it doesn't necessarily mean the intercrop is more profitable than the two monocrops so another measure of Relative Total Value is used to assess income benefits from intercropping. RYT and LER are very similar:

Relative Total Value (RTV), Monetary Equivalence ratio (MER) or Income Equivalent Ratio (IER): the ratio of the area needed under sole (mono) cropping to produce the same income as one hectare of intercropping at the same management level. (*Vandermeer*)

Partial LER: is used to look at the LER of each intercrop component. When they are added together all the Partial LER of each component will total the Total LER for the intercrop. This can be used to see which component is benefitting the most from intercropping.

Nitrogen Land Equivalent Ratio (NLER): adapted version of LER to see the effects of different nitrogen rates on intercrop performance.

Crop Performance Ratio (CPR): calculates the efficiency with which resources such as radiation are used to produce dry matter. A CPR greater than 1 indicates intercrop advantage

Radiation Use Efficiency (RUE): measurement of light use efficiency of intercrops and sole crops

STICS Model: the use of computer models such as STICS to try to predict the outcomes of different intercrops. The problem is the models currently do not include longer term effects of intercropping such as increased N accumulation, increased SOM and their effects on the following crop.

3.c. Why intercrop? The effects of intercropping and the benefits and drawbacks of mixing plant species

> *"In modern crop production, each plant is often almost genetically identical to its neighbours, allowing insect pests and pathogens to move from plant to plant and decimate crop yields if there is no chemical protection. Increasing plant diversity in agricultural fields may reduce pest abundance and damage, and reduce pesticide use. (Tooker and Frank, 2012*)

Below is a good diagram which outlines the positives and some negative effects of intercropping.

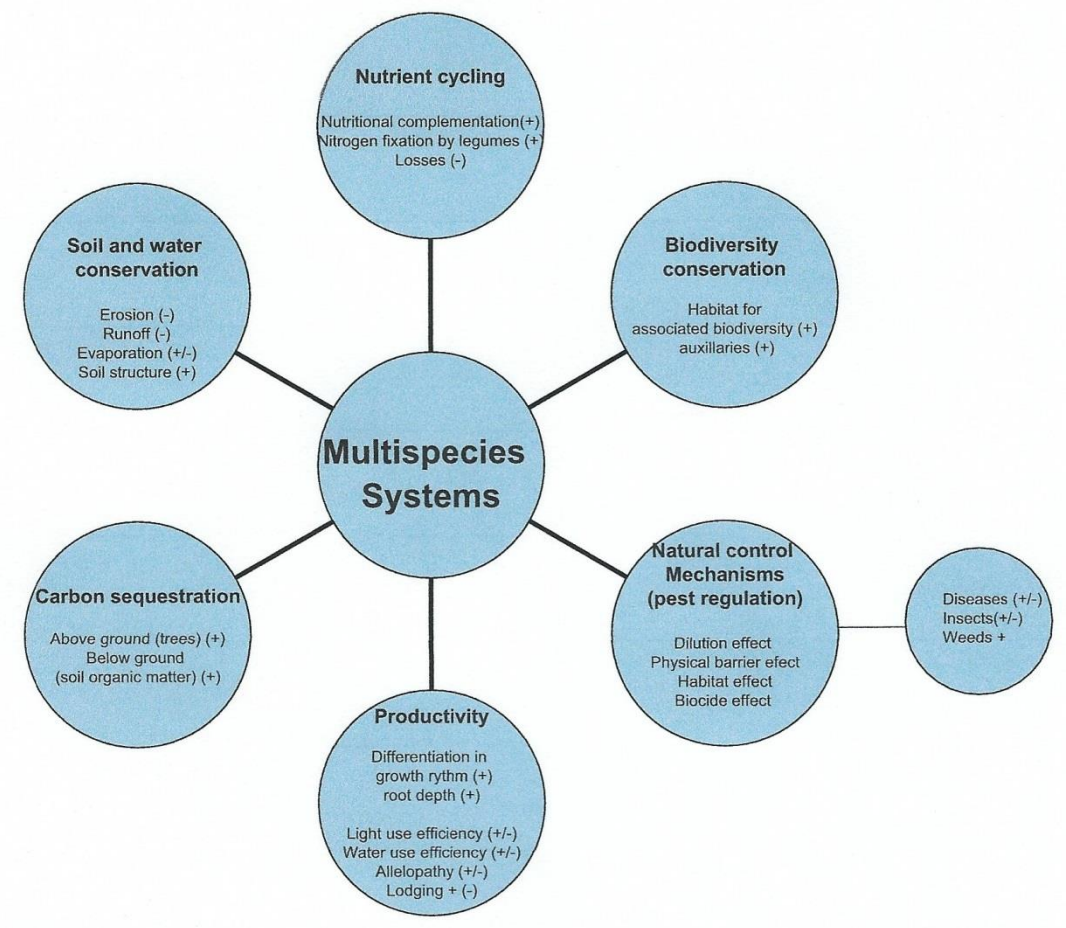

Figure 4: (Figure courtesy of E. Malezieux et al.)

3.c.i. Economic and social factors

Advantages:

- Higher yields (20-30% on average for cereal/legume intercrops) and yield stability leading to higher income and lower risk
- Less inputs needed so lower growing costs
- You can produce more income from a smaller farmed area, meaning more small family farmers can possibly survive keeping people in the rural communities
- If you lose one crop component during the season you still have one component left to harvest (good risk management)

***Disadvantages*:**

- yields can be decreased if relationship between intercrops is more competitive rather than facilitative
- higher risk of failure than a monocrop ***if*** the intercrop is not planned thoroughly

3.c.ii Weeds

Advantages:

- Legumes fix nitrogen(N) from the atmosphere and so in a monocrop they do not compete with weeds for soil N and so you get a high weed biomass. If you intercrop a legume with a cereal or brassica which will compete with the weeds for soil nitrogen you will lower the weed biomass (not necessarily weed number).
- Intercrops can compete for nutrients and water more efficiently than sole crops so compete better with weeds
- Reduction in solar radiation reaching the soil surface in certain intercrops reduces amount available for weeds (e.g. 30% less radiation in wheat/fescue intercrop compared to sole crop)
- Intercrops in general show higher tolerance to weed competition than sole crops
- Weed diversity decreases with intercrops (*Mohler and Liebman 1987*). This is due to the components of the intercrops filling the niche that Mother Nature would fill naturally with a weed species.
- Some weed species only germinate when soil nitrate levels are around 50 ppm; planting cereals with legumes helps soak up the excess nitrates so reducing weed germination. This is not observed as much when using herbicides. Herbicides are doing the job of competition. (Weed advantages of intercrops are generally going to be more pronounced in organic farming where no herbicides are used)
- Higher biomass production above and below ground in intercrops improves soil structure and fertility, which disadvantages weed species that thrive in poorly drained low fertility soils, such as blackgrass
- An alleopathic effect on weeds by an intercrop component can reduce weed biomass compared to a sole crop.

See Disadvantages of weeds on next page

Disadvantages:

- In conventional farming intercropping may mean that some or all herbicides available in sole crops cannot be used as they could kill or damage one or other of the intercrop components
- No benefits to weed control in intercropping when you go over 5 species in a mix but higher diversity does give higher production stability
- Legumes when planted with cereals may leave soils with a higher nitrate level making some weeds worse in the following crop. Only an issue if intercrop mix is not very nitrogen efficient. Should not happen in a properly designed intercrop.

3.c.iii. Disease

Advantages:

- Intercrop effects on diseases include the dilution effect, physical barrier effect, and the chemical effect, which can all lead to lower disease presence
- Intercropping can mean distances between plants of the same species are further which delays disease spread
- In a bean/cereal intercrop Fernandez-Aparicio (2011) found a reduction of 47% of chocolate spot
- Intercropping can change the micro-climate in the crop and reduce crop wetness so reducing likelihood of disease development and spread
- A reduction of 39-78% of Ascochyta disease spread (spore dispersal) in wheat-pea intercrop in France was due to changes in the crop canopy compared to sole crop peas

Disadvantages:

- You can get a higher incidence of mildew in cereal/legume intercrops compared to cereal sole crop as there can be a higher amount of nitrogen present in the cereal intercrop component
- More shading in some intercrop combinations can lead to a moister canopy, leading to higher disease incidence
- Increases in certain plant residues can increase the amount of pathogenic inoculum present for the current crop or the following crop

3.c.iv. Insect pests

Advantages:

- Intercropping effects on pests include the dilution effect, physical barrier effect and the chemical effect
- Andow in 1991 analysed 209 studies on intercropping involving 287 parasitic insects. The insect pests were significantly fewer in 52% of cases.
- You can get a lower pest incidence as one intercrop component can host a predator of an insect pest of the other component(s).

continued overleaf

- Certain plants can emit volatiles to attract beneficial insects (trap cropping) such as garlic in wheat/garlic *IC (Hai-bo 2013*), or repel pests like desmodium repels stemborer moths in maize
- Studies show you get 20% less aphids in the spring from an OSR /bean intercrop compared to sole crops.

Disadvantages:

- You can get more pea/bean weevil damage in a legume intercrop component due to lower plant numbers compared to a sole crop. More pests per plant.
- If one component is a host for a pest of one of the other components of the intercrop, then pest incidence can be increased compared to sole cropping. You need to choose intercrop components carefully.
- Increased shading in an intercrop canopy can lead to improved conditions (shelter) for certain crop pests

3.c.v. Nutrition, soil and other environmental factors

Advantages:

- intercrops can leave less soil nitrogen after harvest than sole crops, so less chance of nitrogen leaching. This was found in Denmark when comparing pea/barley and pea sole crop
- legumes fix atmospheric nitrogen reducing competition for soil N for cereals or brassicas components
- legumes and brassicas as companion crops can absorb large amounts of nitrogen and other minerals during the autumn and winter, then when they senesce they will slowly release them to the cash crop in the spring. (Act as a natural starter fertiliser)
- legumes have different rooting patterns than non-legumes, so less nutrient competition can occur
- some legumes can adapt their root pattern and behaviour in an intercrop:

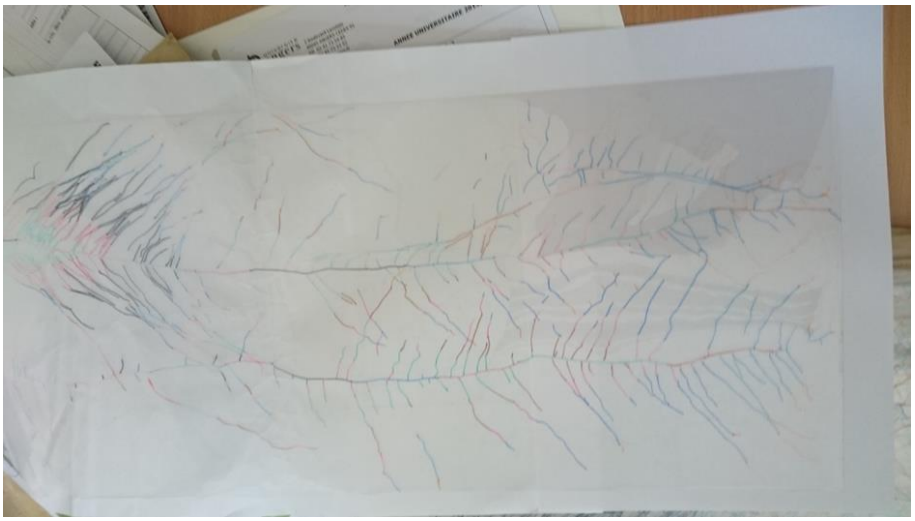

Figure 5: The above picture is of a root trace of OSR (bottom) and beans (top). The beans have mainly rooted near the surface and the rape deep in the soil. This adaption of beans gives root complementarity (*Root trace courtesy of Dr Joelle Fustec*)

- You can get a higher grain nitrogen % (and protein) in wheat when intercropped with a legume (could be due to lower yields in some cases). This could be a way for a low input system to reach bread milling specifications
- Different plants can use different forms of N, so intercrops can utilise soil/ atmospheric N resources more efficiently
- You can get an increased soil carbon sequestration and soil organic matter (SOM) in intercropping
- Intercropping increases crop light interception and Radiation Use Efficiency by plants that use light at different parts of the crop canopy and a different times of the year. (Broadleaf crops intercept more light at midday as their leaves are horizontal whereas cereal leaves are at different angles so they utilise light at a different time of day)
- Barley roots penetrate deeper when in an intercrop
- Legume intercrops and mulches will help balance the soil and residue C:N ratio after a cereal crop helping the establishment of the following crop
- Increased canopy of intercrops can help reduce evapotranspiration and so reduce water loss
- You get less lodging in intercrops. This was seen by Joel Mansson in Sweden when he intercropped peas with oats (cereals act as a trellis for peas)

Figure 6: Cereal/pea intercrop from the Swedish University for Agricultural Science trial plots, Alnarp

- Accumulation of P,K,S is enhanced by around 20% when intercropping pea and barley
  (The figure below shows the mechanisms of P mobilisation in intercropping)

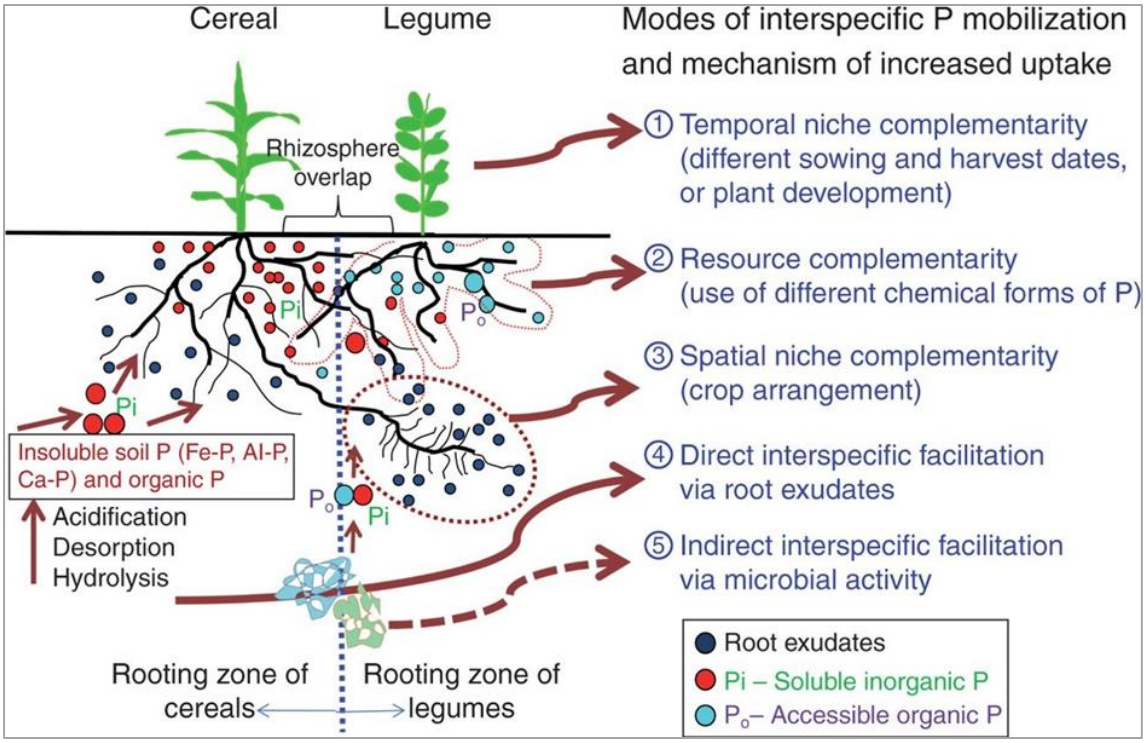

Figure 7: the mechanisms of P mobilisation in intercropping (*Figure Courtesy of Xue et al. 2016)*

- Hydrogen fertilisation of soils by legumes: Hydrogen gas (H_2) is an obligate by-product of the N-fixation reaction. A legume fixing 200kg/ha/N per annum would produce 240,000l of H_2. Most of this is used in the soil and increases O_2 consumption and CO_2 fixation. H_2 influences soil micro-fauna and can in turn lead to nutrient release to plants. H_2 fertilisation increases growth and soil fertility for legumes and non-legumes. This is a relatively unknown benefit of legumes but could explain some of the benefits seen by legume intercropping even if there is little direct nitrogen transfer to non-legume species.
- Legumes increase organic P and Ca levels in the soil through acidic root exudates making them available for other intercrop component species
- Different plants species when senescing release different types of nitrogen and so can give a wide N-release time period if you mix species
- Red clover can alleviate soil compaction near the surface and lucerne can improve drainage (could be important on heavy soils).
- Intercropping of wheat with clover increases earthworm density (*Schmidt et al. 2003*)
- Intercropping increases ground beetle numbers and diversity

Disadvantages:

- if legumes are continuously shaded their ability to fix N is dramatically reduced
- possibility of lower oil content in oilseed crops as there are higher amounts of nitrogen in intercrops. Intercropping increases carbohydrate synthesis and reduces fatty acid synthesis so reducing oils, this though could be managed through lowering nitrogen inputs

- Depletion of soil water reserves in some intercrops can lead to reduction of yield in the cash crop. Wheat /pea intercrop does not use more water in the soil profile than sole crops but wheat/OSR intercrop can use more water at 60cm depth but not above
- In nature species richness can decline as soil fertility increases; this means on highly fertilised soils some diverse intercropping may be difficult if trying to use low fertility crops

The above lists of advantages and disadvantages are by no means complete but hopefully provide a good starting point.

4. Types of Intercropping

Below I will itemise different types of intercropping I have encountered during my research. Some are very similar and may be interchangeable. I have tried to arrange them in increasing complexity and diversity.

4.a. Variety mixtures

This is probably the simplest form of intercropping and may technically not be intercropping as it does not involve different plant species. It involves growing more than one cultivar of a certain crop in the field mixed at the same time. You still get similar benefits and interactions with variety mixture as you do with intercropping of different plant species. It has been proved that you get reduced foliar and soil disease severity and spread, more yield in some cases and more yield stability, though cultivar mixes are unlikely to see much weed benefit. The most foliar disease benefits are seen with rust and mildew in cereals.

Variety mixtures of soft wheat have shown increased grain and alcohol yields. Dr Adrian Newton et al. have produced a good report showing that there are benefits of variety mixtures in Group 3 wheat - http://cereals.ahdb.org.uk/media/309404/pr452-final-project-report.pdf . Dr Newton has also shown benefits of variety mixtures in barleys.

More research on varieties for mixtures is needed and the marketing of mixtures needs developing as most end users want a pure variety product.

Case Study: Martin Wolfe, Wakelyns Agroforestry, UK

Martin is a plant pathologist who owns and runs Wakelyns as a research farm.

Figure 8: Martin Wolfe pictured at Wakelyns Agroforestry research farm

continued from previous page

As a plant pathologist he was interested in the effect that multiple cereal varieties would have on disease spread and severity. Martin told me a story about East Germany in the 80s. There was no cash to buy fungicides so the state funded and co-ordinated work on spring barley variety mixtures. They found that a four-way mix reduced disease dramatically. The Malsters were also involved. It worked very well until the Berlin Wall came down.

I think this story also highlights the need for co-operation between farmers, breeders, researchers, state and end users for these low input methods to be successful. When you have a mixture you should have at least four cultivars and you also need to rotate the cultivars in and out of your mix each year. Martin also talked about induced resistance. This is where one variety gets a disease and this triggers disease resistance mechanisms in the other varieties. Martin has also been involved in the Wakelyns Wheat Populations Research. They have made a variety of wheat in which all the plants in the field are genetically different. The idea is that they will have different susceptibilities to disease and also different preferred weather conditions. This means that disease should not spread easily and also it is more adaptable to different weather extremes. The problem with this population is that they do not include any modern high yielding varieties and so yields are lower, so more suited to organic farming. Martin believes variety mixtures including modern varieties would suit conventional farming. He also has a real passion for Agroforestry, I will deal with this subject later in the report.

Recommendations:

- Use variety mixtures whenever possible including in monocrops
- Use at least four varieties and rotate the varieties each year
- Check your end user will accept variety mixtures before planting
- Add variety mixtures to your intercrop components. When the Wakelyns's Population variety was used in a wheat/bean intercrop it yielded 68% higher than non-variety mixture intercrop
- Choose varieties with different growth habits and disease ratings to spread risk
- Variety mixtures should not be limited to cereal crops but the theory applies to all crop types

4.b. Strip Intercropping

Definition: *the growing of a cultivated crop in strips alternating with strips of a sod-forming crop (as hay) arranged to follow an approximate contour of the land and minimise erosion*.

Above is a definition I found of strip intercropping that suggests that the idea came about to reduce erosion on sloping fields. The strips of hay would act as a buffer to soil and nutrients to stop them

running downhill. There is no indication of how wide the strips should be; I think this is down to the farmer's discretion, crops being grown and machinery sizes.

I have not found many farmers who are actually practising strip intercropping. I guess that is because farms are larger, and also the practicalities of running large machines over large acreages. Also the "Dustbowl" is hardly now within living memory so soil erosion measures have been forgotten about. There are, however, some examples of what some call "row intercropping", where crops are grown in alternate rows. This is a small scale version of Strip Intercropping. I did though visit Bob Recker in Iowa and his story is below.

Case Study: Bob Recker, Cedar Valley Innovation, Iowa, USA

Bob is a retired engineer from the nearby John Deere factory. He has now made himself even busier than before he retired by undertaking general field trials for farmers and investigating the potential for Strip Intercropping.

Figure 9: Strip intercropping. Picture courtesy of The Corn and Soybean Digest

The above example is the growing of maize and soya beans in strip intercropping. You get an "edge effect" on corn meaning the outside rows of maize yield higher than the middle rows, as shown on next page with a picture of maize cobs from a strip, courtesy of Bob.

The maize at the edge gets more light and the narrow strip helps cool the crop. This effect means you can increase the seed rate on the outside rows and get a large yield increase. The ideal width of the corn strip is 3 meters according to Bob. The soya bean yields are slightly down in between the corn but the overall net benefit was $100/ac. This worked well when "Round-Up Ready" corn and

continued from previous page

soya did not have any glyphosate resistant weeds. Now, though, there are many resistant weeds, which means that alternative chemistry has to be used for weed control, which kills either the corn or the soya and so this practice is now impractical on a large scale. Bob was trying to work out how to still get the benefits of the edge effect and was experimenting with wider rows in corn. I think there would be other options for this to work if you alternated the corn strips with a winter cereal such as wheat, oats or barley. Then the herbicide issue would not such a problem. The issue in the Midwest would be convincing a farmer to grow anything apart from corn or soya!

Figure 10: maize cobs from a strip. Picture courtesy of Cedar Valley Innovation

I also stayed on an organic farm in Nebraska with Liz Sarno and her partner Larry and they were practising something similar, growing strips of crops

Figure 11: growing strips of crops on Liz Sarno and Larry's organic farm

Larry was practising strips due to the benefits of the edge effect and also to encourage pollinators (add diversity).

I also saw at Gabe Brown's farm, in North Dakota, a field of corn where he had not planted the whole field to corn but put some of the field into a cover crop - he felt the whole field was too large for just one crop. This I feel is a valid concern. In large fields of a single monoculture you are unlikely to have diversity of insect predators, especially when predatory insects only travel a certain distance from the edge of a crop, around 250m. If you are trying to reduce pesticide use and pest problems then in large fields it is going to be difficult.

When in France I visited farms with mouse problems. Their fields were very large and there was little or no habitat for mouse predators. I feel they would benefit from smaller field parcels or in field predator habitats, such as beetle banks.

At first I did not think that Strip Intercropping had a place in the UK but now I believe it may have some practical uses in certain situations

Recommendations:

- Maize and winter barley undersown with clover. On steep slopes, where growing maize causes large amounts of erosion, having strips of winter barley undersown with clover growing between strips of maize would help reduce erosion. Once the barley is harvested the clover would grow and act as a barrier to water and soil run-off. Also you would get a yield increase in the maize due to the edge effect. This practice would also be good for root and vegetable growers in the UK. I think if you alternated 24m of maize and barley to fit sprayer widths, it would be a great help in reducing soil erosion
- Plant wider rows of beans to get an "edge effect". I have observed this spring that the outside of our fields of beans or the rows next to tramlines always seem to have more pods. This could be partly due to more sunlight for the plants and maybe the plants are easier to access for pollinators which increases pod set. We have planted beans in 24 inch rows before and got the same yield as 12 inch rows. The problem is that you get more weeds in the wider rows. This could be reduced by growing a weed mulch in the bottom of the beans.
- Developing countries where people are cropping hillsides: strip intercropping would help reduce erosion
- Vegetable operations where you want to get pollinator benefits: alternating crop strips and adding pollinator strip could be an advantage.
- Market gardens: to reduce erosion and reduce pest and disease spread

4.c. Relay cropping

Definition: *Relay cropping is a version of double cropping, where the second crop is planted into the first crop before harvest, rather than waiting until after harvest as in true double-cropping.*

Double cropping rarely happens in UK arable farming because our warm season is not long enough to enable two crops to mature in the same year. In other parts of the world (nearer the tropics) it is possible to get more than one crop harvested per year. There are areas like the Northern USA where

double cropping can be risky if the summer and autumn weather is poor and the second crop yields badly or doesn't get harvested. This is where relay cropping has been developed.

The idea of planting the second crop into the standing first crop means that when the first crop is harvested, the second crop is already growing and so takes less time to come to harvest than a true double crop and potentially has a higher yield. Relay cropping is very similar to undersowing which is sometimes practised in the UK. The main difference with relay cropping is that you take the second crop to grain harvest whereas an undersown crop you leave as a mulch, graze, or treat as a cover crop.

There are two main issues with relay cropping: you need machinery that can plant into a standing crop without damaging the main crop and the timing of the planting of the second crop is key and weather conditions may prevent planting at the ideal time. I was lucky enough to visit Dustin in Ontario who knows about relay cropping.

Case Study: Dustin Mulock, Ontario, Canada

Dustin was a last minute visit that was organised through Twitter. I only had a short time with Dustin and wish I could have had more: the reason is because Dustin exemplifies the idea of "have a go and make it yourself, farmer", which I love. Dustin has been relay cropping soya beans into winter wheat. Not only does he relay soya into wheat, he has managed to bale and collect the bales from the wheat, with minimal damage to the soya, by designing and making his own bale trailer and adapting his baler.

See pictures overleaf

Dustin says that he does not get a drop in yield of wheat but only gets one third of a crop of soya. However he only uses home-saved seed, increases the seed rate and keeps the costs very low.

Another interesting thing he said is that establishment can be difficult due to drought and so he plants the soya deeper to find moisture. This could be a real issue too in the UK where we are planting an interseeded crop into a cereal in May when the crop is using all the moisture. Planting depth could be critical.

continued overleaf

Figure 12: picture courtesy of Dustin Mulock

The above collage shows (clockwise from the top left):
Dustin planting the soya beans into wheat
Harvesting the wheat with the soya in the bottom of the crop
Baling the wheat straw and then
Collecting the bales - real farmer ingenuity.

Row widths are critical to the success or failure of this practice. Above Dustin was growing twin rows of wheat at 8 inches apart and then 22 inches between the rows of the twin rows. I think in the UK 22 inches between rows would reduce yields. 10 inches seems to be the accepted standard before you see a yield drop. The question is whether 10 inches is enough of a gap to allow for the relay crop to not be shaded out. I am not sure. Main cash crops with very erect growth habits would help.

With modern machinery such as the "System Cameleon" (explained in the machinery section in Chapter 6) and modern RKT guidance systems, I think relay cropping has now become a real option for UK farmers. We need research and trials, though, into: shade tolerant summer crops that can cope with being sown into cereals, row widths, planting timings, seed rates and many more issues. The

application of slug pellets would need to be considered at planting and also whether any previous herbicide has been applied that would affect the second crop.

Recommendations:

- Buckwheat and red clover sown together into a standing cereal, then harvest the buckwheat in the autumn
- Sunflowers and a cover crop mixture into the standing cereal. If you don't get the sunflowers to harvest you will still have a cover crop growing. Whether cereal would shade the sunflowers or whether the sunflower may grow too tall before wheat harvest needs to be considered. So winter barley may be a better option than wheat due to its early harvest.
- Plant millet and some companion species into a cereal and then harvest the millet in the autumn
- Just using this method to plant a cover crop would save time after harvest and hopefully increase biomass of the cover crop.

4.d. Temporary intercropping/companion cropping

Companion planting definition: "*The close planting of different plants that enhance each other's growth or protect each other from pests*"

When I first heard about anything to do with Intercropping, while listening to Frederic Thomas speak about growing OSR with vetch and buckwheat, the companion crop was always temporary and only stayed with main crop for part of its life cycle, and I now associate this type of intercropping with companion cropping. It was not until I started to research companion cropping that I found many gardening books which described the definition I outlined at the start of this section. In reality "companion cropping" could be used to describe all of the types of Intercropping in this report; this is why it is in the report title. However, due to my first encounter with companion cropping, I am going to put it in here with temporary intercropping. Sorry for the confusion! Temporary intercropping is where a plant species is only there for part of the main crop life cycle/or is not taken for harvest but is planted at the "**same time**" as the main crop.

See case study on next page

Case Study: Robin Griffeth, Kansas, USA

My visit to Robin was very brief but is a visit that I think about a lot as Robin has shown what can really be possible with companion cropping. Robin with his son Kelly grows wheat, barley, triticale, sunflowers, sorghum, milo and soya beans. It was his double crop sunflowers that I had come to speak to Robin about. A few years ago Robin planted a cover crop mix after wheat harvest. Later in the year he thought that the sunflowers in the cover crop were worth harvesting and to his surprise they out-yielded his monocropped sunflowers! The following year he grew some companion cropped and some monocropped sunflowers. The monocropped sunflowers failed and the companion cropped sunflowers survived. Robin now only grows companion cropped sunflowers. The mix for 2015 is below:

Companion crop species	*Seeding rate (lbs per acre)*
Hairy vetch	*10*
Red clover	*1*
Chickling vetch	*5*
Austrian winter peas	*5*
Iron and clay cowpeas	*5*
Pearl millet	*1*
Wildlife grain sorghum	*2*
Cereal rye	*15*
Nitro radish	*0.3*
Rapeseed	*0.3*
African cabbage	*0.3*
Broadleaf mustard	*0.3*
Peredovic sunflower	*0.5*
Safflower	*0.5*
Flax	*1*
Buckwheat	*1*

Figure 13: Robin Griffeth's intercropping mix.

The case study of Robin Griffeth continues on next page

As you can see from the photo of the label above there is a huge amount of diversity in the mix. This allows Robin to grow his sunflowers without insecticides or fertiliser.

Figure 14: the sunflower mix growing on Robin's farm

This is a win-win situation for the farmer, the soil and the environment and looks beautiful!

Figure 15: sunflower crop in bloom. Photo courtesy of Robin Griffeth

The other fascinating part of this story is that Robin showed me the crop of triticale that followed the sunflowers. It had needed no fertiliser either due to the benefits inherited from the companion cropped sunflowers.

A couple of reasons that this intercrop has been so successful for Robin is, I believe, because you have a large physical difference in size between the cash crop and the companions, so harvesting is not an issue; in addition the above ground competition is reduced. Also the crop is not there for long so not all the companions have the chance to go to seed. It does show, though, how some of the best ideas can come when they are not intended - or even mistakes!

An example of temporary intercropping and companion cropping I saw on my travels was on Freidrich Wenz's farm. He had planted spelt wheat with red fescue (9kg/ha), red clover (1kg) and white clover (1kg/ha). Clovers are 10% of the mix. Crimson clover is more frost susceptible than red clover so may be a better choice if you don't want the clover to survive the winter. The red fescue stays low and does not compete with crop. The important thing to remember is that Freidrich does not use artificial nitrogen. If he did I think the mix would overtake his wheat and more weeds would grow. What Freidrich is doing is planting a grass in his wheat that he wants to be there. If he did not, then Mother Nature would add one for him. Grasses add energy to the system and encourage mycorrhiza. It can be a mistake to exclude grasses from the mixes as long as they don't compete. Velcourt have trialled oats planted with winter wheat for blackgrass control with some varied success. In this case the oats are having some alleopathic effects on grass-weeds and filling a niche.

Temporary intercropping of Durum wheat with faba bean where beans were hoed at cereal shooting led to wheat in the intercrop being taller; the flag leaf senesced a week later; there was an increase in N of 48kg/ha; grain protein increase; less disease; specific weight increase and an increase in yield *(Tosti 2010)*

Temporary intercropping of cereals is one technique that I believe has huge potential in the UK and is discussed further later in the report. It needs to be remembered though that in most cases it will not be possible to use a pre-emergent herbicide. Also, when choosing you temporary intercrops for cereals, it may be an idea to choose species that die with frost or can be killed. One real benefit is that you get the species interactions early in the crop's life but do not get the competition issue during sensitive growth stages.

Recommendations:

- A British version of Robin Griffeths's success would be to try spring oilseed rape with a large variety of low growing legumes and cereals. You would want cereals that were winter varieties that needed vernalisation and so would not go to seed.
- You could try to grow sunflowers with companion plants here in the UK but I think we may need a bit more global warming before it would be consistently successful.
- Nicolas Courtois in Geneva was companion cropping wheat with lentils, Egyptian clover, vetch and beans. All at the same time: see photo on next page.

  Some of these will survive the winter and other will not.

Figure 16: Nicolas Courtois in Geneva was companion cropping wheat with lentils, Egyptian clover, vetch and beans

- The options for cereal temporary intercropping are huge.
- This year we planted oats with our spring beans. See photo on next page

The original idea was to grow as a full season intercrop and harvest both but, due to grass weed pressure, we sprayed the oats out. It, though, has not been a waste of time. The main idea of the oats is to suck up soil N, which should reduce weeds and also force the beans to nodulate. This should lead to higher yields.

Figure 17: Spring beans planted with oats on my own farm

4.e. Full season (synchronised) intercropping

These types of intercropping systems involve the components being planted together and harvested at the same time. These commonly involve 2 intercrop components - such as a cereal and legume – together, or a brassica/legume mix, but can involve more than 2 crop components.

Case Study: Scott Chalmers

I really wanted to meet Scott as he is a leader in the field of growing canola and peas together (peola) as an intercrop. I have grown peola myself and believe it to be a really viable crop in the UK. Scott has been trialling peola for WADO for a few years and has written several annual reports for the WADO organization on the subject. (The 2014 Annual report can be found here: https://www.gov.mb.ca/agriculture/innovation-and-research/diversification-centres/pubs/wado-annual-report.pdf). Like most of the area they had had late frosts which had killed some of their canola but they still had the peas for harvesting which shows that intercropping is a good risk management tool.

Figure 18: Peola crop in Manitoba after a hard frost

During his own trials growing peola, Scott has implemented various agronomic guidelines that other researchers have discovered about peas:

- *if combined fertiliser and soil nitrogen levels exceeds 55 kg/N/ha, adding nitrogen fertiliser will reduce nodulation (nodulation is an energy intensive process: if legumes do not need to nodulate, they won't bother)*
- *if soil nitrogen levels are less than 10kg/N/ha at planting, legumes may incur a nitrogen deficiency early in their development, so a little starter fertiliser may be appropriate.*
- *Peas leak nitrogen which accounts for 22-46% of the soil's nitrogen budget*

Through his own research Scott himself has discovered the following when growing peola:

- *peas and canola prefer to be mixed within the same row, not in separate rows*
- *if you add fertiliser to peola the peas will use this fertilizer and can act as a weed, not a companion, instead of the fertilizer being used by canola.*
- *adding nitrogen fertiliser does not add to total yield. Generally peas do not respond to nitrates while canola will, but often peas will dilute responses by stealing it from canola*
- *Canola in peola hardly responded in yield to nitrogen fertiliser*
- *Growing peola in mixed rows uses more soil moisture than dividing rows into individual crops like double or triple rows*
- *Mixed row peola (compared to monocrop or individual row intercropping like single rows of each crop) may assist with the crop, dealing with excessive moisture conditions.*

- *Peola decreases the incidence of seed borne disease and harvest split damage in peas*
- *Peola decreases risk of shatter in canola during wind storms compared to monocrop canola*
- *Total LER for this system range from 1.1 to 1.6 with an average of 1.2*

Scott has come to the conclusion that you should grow the peola with the peas as the main crop, and lower the canola seed rate and use it as a subsidiary crop to help keep the peas from going flat (a trellis). Scott suggests that the canola is simply wicking up excess nitrogen and soil moisture that the peas do not use.

With Scott I had a tour around the area. We saw a field with sunflowers and vetch where vetch was broadcast before sunflower seeding. (See photo below). You get 60kg/ha of nitrogen from vetch as a companion, 80% improved weed control, increased SOM by 0.25 in one year and no yield deficit.

Figure 19: Scott, above, standing in a field of sunflowers and vetch

We also saw a barley/mustard/peas/clover mix and a camelina/peas mix. Below is a mustard/peas and alfalfa mix.

Figure 20: Above is a mustard/peas and alfalfa mix

We also saw a barley/mustard/peas/clover mix (above) and a camelina/peas mix.

It was a fascinating two days with Scott with lots of potential ideas for the UK.

Other studies suggest that you get fewer issues with flea beetle when OSR is intercropped with pea. Also pea/rape intercrops are more likely to over-yield that pea/barley due to the fact that barley is more competitive than rape.

Recommendations:

- Peola is a no-brainer on the right soil type. It is proven to work in the UK. I would echo Scott in saying: plant a pea crop with a little OSR added to reduce lodging
- Pea/canola/lentil – 30-40% over-yielding for Colin Rosengren in Canada

4.f. "Push-pull" and trap cropping

Definition: *The push–pull technology is a strategy for controlling agricultural pests by using repellent "push" plants and trap "pull" plants.*

This system of intercropping is best described by the example in my case study below.

Case Study: Dr Zeyaur Khan, ICIPE, Kenya

Dr Khan and his team have developed the "push-pull" technology for growing maize. It is probably one of the most impressive uses of intercropping to have been developed that has positively affected so many people. (About 110,000 farms and growing). One of the problems with growing maize in East Africa is a parasitic weed called striga. It attaches to the roots of the maize and sucks up all the goodness. Another major problem is the stem-borer that reduces yields in maize. The picture below explains how the technology works:

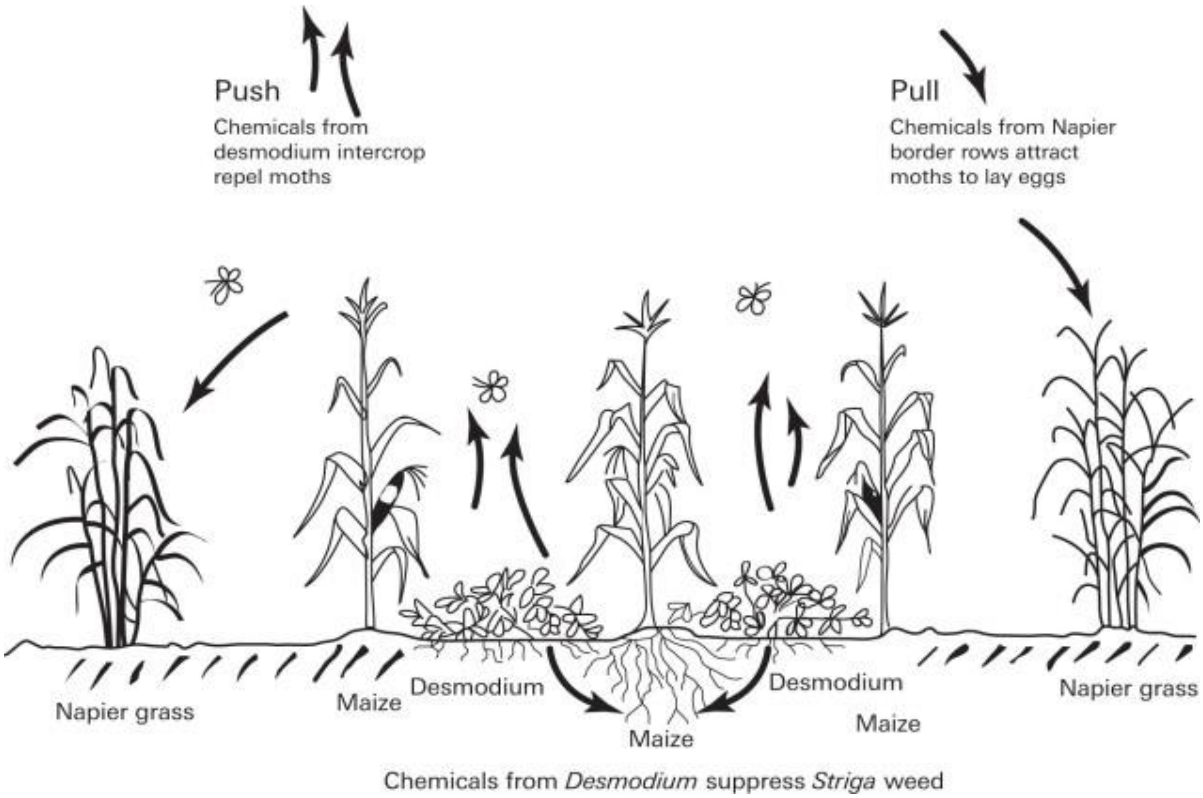

Figure 21: Push-pull technology. (Figure courtesy of www.push-pull.net)

The desmodium produces chemicals which repel the stem-borer moth and the Napier grass attracts the moths into it and out of the maize. The desmodium also causes suicidal germination of the striga weed. So the use of desmodium as an intercrop with maize and Napier grass around the edge of the field as a trap crop solves two problems of growing maize in East Africa. This intercrop design has increased maize yields by 80% (1.5t/ha to 5t/ha).

On next page is a picture of with and without "Push-Pull":

The Napier grass that is grown around the outside of the field is cut for fodder. The desmodium is a nitrogen-fixing perennial and can also be used to feed chickens. This means that the farmer not only gets more maize to feed himself and his animals but fodder for his animals too. This system also works in sorghum and millet. There is no patent on this system, it is farmer owned. The system also really improves soil carbon sequestration and soil health: a really amazing use of intercropping technology.

Figure 22: demonstrating with and without push-pull

Push –Pull systems are so unique that I am not sure whether it could be for crops in the UK. I hope it can: a system for insect pests in pulses would be great as they seem to suffer from multiple pest attacks. Trap cropping by itself is utilised in other crops around the world. A definition of trap crops (Shelton and Badenes-Perez, 2006):

> *"Plant stands that are, per se or via manipulation, deployed to attract, divert, intercept and/or retain targeted species or the pathogen they vector, in order to reduce damage in the main crop"*

I came across one example in the UK when I visited Rothamsted and spoke to Dr Sam Cook who specialises in IPM in OSR. She is trialling turnip rape as a trap crop for pollen beetle. She puts a 6m border of turnip rape around the field of OSR. The turnip rape flowers 2-3 weeks earlier than the OSR and the pollen beetle prefer the volatiles of the turnip rape.

I was also lucky enough to spend a day with Dr Jonathan Lundgren who at the time was an entomologist working for the ARS in South Dakota. Jonathan is trialling Oilseed crops which he is growing as buffer strips around fields of soya beans. He is growing canola, borage and cuphea.

See picture on next page

These crops flower at different times and he is looking at the effect on soya bean aphid in the main crop. The idea is that these buffer strips can be harvested and give an income to the farmer. He thinks this is the only way he is going to get US farmers to plant pollinator strips. I think this is a great idea and brings diversity into the field.

Figure 23: buffer strips in South Dakota

We also talked about the trouble we had with bruchid beetle pests in the UK and he suggested Hungarian vetch as a crop that is attractive to bruchid. You could plant this around bean fields and either hope that the bruchid stay in the vetch, or spray the vetch strip with insecticide and not the beans.

Recommendations:

- Grow strips of Hungarian vetch around bean fields for bruchid control and harvest vetch. Could add rye to the vetch to keep vetch up and harvest both
- Grow strips of buckwheat around beans fields to increase pollinators and harvest buckwheat
- Grow phacelia in strips around flowering cash crops to encourage pollinators and then harvest.
- The benefit of growing these niche crops in strips and not whole fields is that you lower your risk. If you lose the crop before harvest you have still had a benefit to the main cash crop
- Use trap crops as part of our Environmental Focus Area (EFA) requirement. A good way to utilise "non-cropped" areas.

4.g. Undersowing

Definition: *"Undersowing (or oversowing) is the sowing of a secondary crop underneath the primary cash crop."*

Undersowing is very similar to relay cropping. The difference in terms of this report is that undersowing is normally when you plant a crop that will become a pasture for the next year or a cover crop for the following summer or winter, whereas in relay cropping you harvest two combinable crops in one year. Undersowing is a very old practice that used to be very popular when farms were mixed with crops and livestock. The specialisation of crop farms and the introduction of artificial inputs have

meant that undersowing has almost disappeared. Now, though, I believe it has huge potential on crop farms for a numbers of reasons. The undersown crop can provide nitrogen to the system (mostly for the following crop), improve soil health and structure, act as a weed mulch and allow a cover crop to be established before the harvesting of the main cash crop. In no-till where you have a lot of residue the post-harvest growth of a mulch will help balance the soil C:N ratio leading to easier establishment of the following crop.

The Organic Research Centre has a good publication which covers species suitable for undersowing, found at the following link:
http://www.organicresearchcentre.com/manage/authincludes/article_uploads/iota/technical-leaflets/green-manures-species-selection.pdf

Case Study: Josef Appell, Sweden

Josef manages a farm in Southern Sweden that is part conventional and part organic. He uses the same drill, a System Cameleon, for both farm systems. The System Cameleon is a drill and an inter-row hoe (described in the machinery section). This means that Josef can undersow successfully as the drill gets the seed planted in the ground rather than it being broadcast and rolled. This means there is a much better establishment than broadcasting. On his last hoeing of his organic spring barley and organic spring oats Josef will plant either white clover, which will become a seed crop for next few years, or a mixture of crimson and Alexandria clover. These will give him some nitrogen for his next crop, improve the soil and be fodder for sheep. Josef being an inventive farmer has tried to plant oats directly into white clover.

He was hoping that the clover would act as a weed-mulch and give the oats a weed-free start but unfortunately the clover was too strong and has competed with the oats. This highlights the importance of getting both crops at the correct growth stages so they don't compete with each other. The clover has done a great job of improving the soil though.

Josef will not give up experimenting, though, with this one failure. I am sure he will find the solutions. Having a System Cameleon at his disposal gives him so many options. It will be interesting to follow his future progress.

See photos on next page

Figure 24: oats and clover growing on Josef's farm

Figure 25: the clover has done a great job of improving the soil on Josef's farm

Recommendations:

- Undersowing of black medic/ lucerne/ red and white clover (separately) at GS22 (tillering) in wheat. The idea is that undersown crops will be less competitive when planted at GS22. In trials there was no reduction in yield at harvest if dry matter ratio of wheat to legume does not exceed 20% legume. If the ratio was higher you got a reduction in yield. Also in the same trials medic and red clover had the highest biomass at harvest followed by lucerne. Medic and red clover can reduce protein the most but they were the most competitive against weeds, so should be targeted at weedy fields. My preference would be to plant them all together to make the most of diversity.
- Dr Randy Anderson showed that seeding mammoth red clover into winter wheat in the spring reduces weed biomass after harvest by 98% (a glyphosate replacement?) The red clover reduced wheat volunteers from 50 plants/m2 to 1/m2. Red clover reduced brome plants from 60 to 9 plants per m2. Competition from red clover made brome more susceptible to winter kill. In the control, downy brome produces 9500 seeds/m2 but in red clover only 23 seeds/m2. Winter wheat yield was not affected by clover but spring wheat was. (17% lower). This is an option in the UK especially for no-till farmers and also organic farmers striving towards organic no-till.
- Oats and barley cope with clover competition better than wheat or triticale so this should be considered when undersowing.
- Spring cereals should be undersown whenever possible
- With crimson clover you can get very aggressive rooting; you don't want root fighting. So if adding to a cereal make sure it is only a small part of a mix
- Other countries grow spring cereals with sweet clover undersown. Sweet clover is a biennial and can become competitive in the second year so may need calming with herbicide and also can become a weed. So as with the crimson clover it is probably best in a mix of clovers, or take the sweet clover to seed in year two for income.
- Red clover is very competitive in wheat but is good on heavy ground, so a well-managed undersown red clover could help improve heavy clay soil structure.
- When visiting Switzerland I saw farmer Ivan who added red clover to his OSR then kept it growing in the wheat. He got 1t/ha less of wheat but 2% higher protein. He killed the red clover in the wheat in the spring, but too late. Earlier kill of the clover could reduce yield loss. As with all clovers there could be potential to increase grain protein in a low input system. This needs further investigation.
- I would always recommend to plant undersown crops rather than to broadcast. Broadcasting it too inconsistent unless you are farming in a wet climate.

4.h. Living mulch /Bi-cropping

Living mulches are similar to undersown crops in their function but they remain under the crop all season long - and even for more than one season. Living mulches have various proven benefits:

continued on next page

"Living mulch systems have been shown to take up excess nutrients, enhance soil physical characteristics, improve weed and pest control and increase biological diversity" (Hartwig and Ammon 2002)

A deep-rooting living mulch such as lucerne has been proved to bring up calcium and other nutrients from deep in the soil which would have otherwise been out of reach to annual crops. Jonathan Lundgren in the USA could not get aphids established in wheat after a lucerne crop due to the high numbers of predators. This shows the potential for insect control/reduction in aphid-borne viruses.

The main issue with living mulches is that if they are not managed properly they can reduce the yields of the main cash crop. Carof (2007) in France, after three years of improving management, managed to get no yield penalty in mulches of sheep's fescue, white clover, bird's foot trefoil and lucerne. So if you understand the pitfalls you can avoid yield penalties with living mulches.

In living mulches the plant species that dominates early in the spring will dominate for the rest of the growing season, so you want the cash crop to be the one dominating. A thick mulch in early winter will reduce plant numbers of cereals so this needs to be managed. Stem elongation, flowering and reproductive periods are sensitive growth periods for cereals. This is when you need to make sure the mulch is not competing. The grain fill period is not a sensitive one, in terms of yield, as grain weight was found to be similar with or without a living mulch, but a high amount of legume biomass after cereal flowering leads to lower cereal protein. If a mulch is not managed properly during stem elongation then number of spikes per tiller is reduced, which reduces yield.

Good herbicidal management of a mulch at the key periods outlined reduces light and other resource competition with cereals. In organic cereals herbicidal management is not an option. Mechanical brushing of clover in wheat before growth stage 39 is an option though: in trials one brushing increased cereal yields by 31%, two brushings gave an increase of 1.31t/ha. Grain N content increased by 13-25kg/N/ha. Brushing tripled N transfer to wheat. They found the best timing of the brushing is once at GS30 and then at GS37. Two brushings gave an equal yield to monocrop wheat. Increase in protein could pay for brushing, though the biggest benefit is probably in the following crop.

Competition for light is more likely than competition for nitrogen in a living mulch. When artificial nitrogen was added was added in trials then competition for nitrogen was not seen. In conventional systems you can use artificial nitrogen to tip the balance towards the cereal especially in the early part of the season. Use too much artificial nitrogen though and the benefits of a mulch will reduce.

Sowing width of wheat in a mulch needs to be considered as it affects wheat yield. In trials it was found that a 25cm wheat row width is the best due to reducing intraspecific competition of wheat.

In dry years white clover can compete with the cereals for water and so reducing wheat yield. So each farmer needs to consider whether white clover is the best mulch for their area: probably not if they farm in a dry area.

Annual legumes are less competitive with the cash crops than perennial legumes in a mulch, but the cost of reseeding annuals is one downfall. If a living mulch is well managed it will bring more benefits than an annual undersown legume. You don't get much N transfer in an annual legume intercrop but you do in a permanent mulch, as legumes such as clovers take 6 months to establish.

This leads on to living mulch establishment. You ideally need a period of 4-6 months of mulch growth, with little competition, before the mulch will withstand herbicides or mechanical damage. Finding this period of growth is not always easy. You need to be really careful to manage slugs and mice in a living mulch, especially in the early stages of establishment and when you are subsequently establishing cash crops.

Trials have shown that perennial weeds were worse in a lucerne mulch compared to a red clover mulch but the red clover can be more competitive to the cash crop.

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Case Study: Hubert Charpentier

Hubert was one of my first visits and probably the one I am asked about the most. Hubert is a farmer in France and is known for his work on growing lucerne as a living mulch with his arable crops. He grows winter OSR, winter wheat, durum wheat and winter peas. Hubert plants lucerne with his winter OSR, and the lucerne grows in the bottom of the OSR all year. (See below)

Figure 26: Hubert Charpentier's lucerne growing in the bottom of OSR

continued on next page

Once the WOSR is harvested the lucerne can grow away. Hubert harvested 3.8t/ha of OSR with lucerne and 4t without. Lucerne needs at least five months to get established which is why he grows it under the WOSR and uses no broad leaf weed herbicides. In this time the lucerne can get its roots down deep and once the lucerne has flowered it can tolerate low rates of herbicides. Hubert prefers lucerne to white clover as lucerne has a deeper root system and so it does not compete with the cash crop for water. Once the WOSR is harvested the lucerne grows all summer and then Hubert no-tills wheat direct into the lucerne. This is where the real advantages come from the living mulch. Hubert uses very little grass-weed herbicides in wheat, only around half the normal nitrogen rates and a lot lower fungicides rates, if any.

Figure 27: wheat and lucerne growing together on Hubert's farm

Above is the wheat and lucerne growing together during my visit. Wheat yields without lucerne were 7.8t/ha with 180kg/N/ha of fertiliser, with lucerne 8t/ha with 100kg/N/ha

Responses to fungicide foliar and seed dressings were: with fungicides and no lucerne he got 8t/ha of wheat yield; without fungicides and with lucerne 7.8/t/ha. After the winter wheat he plants durum wheat with the lucerne and then follows with winter peas where he kills the lucerne. The living mulch gave him a cost saving of 140 euros per ha on chemicals, fuels and fertiliser. Hubert's work has real potential for the UK with a little research and adaptation and is a real option for UK growers to grow low input crops while improving soils.

NIAB TAG in UK has been trialling a living mulch of white clover in wheat for ten years. In the first year they established the clover in August and delayed the drilling of the wheat. The benefits they have found are a tripling of water infiltration rate and reduced soil bulk density. It works best when lowering

N rates. At full N rate you only get a 0.2t/ha yield increase but at zero N you get a 1t/ha increase. It highlights the fact that you need to reduce inputs for living mulches for them to pay for themselves. A 50% N rate would be a good rate. The clover also recovers better after lower N rates.

In Germany they have found that white clover as a mulch can be too competitive due to its undetermined life cycle. This though could be managed through herbicides or inter row mowing. Annual inputs of nitrogen from white clover can be between 150-300kg/N/ha. The amount transferred to the cereal is about 10%. Defoliation of clover increased N release through root and nodule death and increases that percentage available to the cash crop.

Recommendations:

- I think lucerne as a living mulch has potential in the UK but I feel you need to be careful not to overlay an annual monoculture with a perennial one, which would lead to soil disease issues. This is why I would prefer to see a mix of legumes in my living mulch
- Cultivar choice: choose cultivars of the cereals that have high leaf shading ability which can help cereals cope with mulch. You need a cultivar with fast early growth, rapid height growth, most of leaf area in the top of the canopy, and high specific leaf area. Mixed cultivars would help too
- Continuous yellow trefoil planted with spring cereals used to be practised in Kent, my home county, apparently. Maybe this is an option for the future.
- Use winter dormant varieties of lucerne to reduce competition
- Plant lucerne with red clover and a grass to help it establish and use for forage in first season.
- Barrel medic is an option as a living mulch. It is fast growing in the autumn so can establish well (maybe too well in a wet/warm autumn) but not too winter hardy so could allow cereal to compete in spring
- In conventional agriculture nitrogen applications should be reduced in a living mulch. It was found in trials that applications of nitrogen fertiliser in early spring were partially taken up by clover reducing amount available to wheat. Injecting N next to wheat would help reduce this effect.
- Subterranean clover can be used as a living mulch but is more suited to a Mediterranean climate. Plant breeding is needed to find varieties better suited to the UK
- The whole idea of a living mulch needs more research under UK conditions

4.i. Pasture cropping and livestock integration

Farms that have crops and livestock have the easiest options for integrating intercropping into their system. If an attempted full season intercrop does go wrong due to weeds or weather, then a livestock farmer can cut and bale or ensile the crop and still make use of the biomass. Livestock farmers can also make use of undersown crops, living mulches or cover crops by grazing or taking a fodder crop before or after the main cash crop. They are able to spread and lower the risks of intercropping.

Mapleton Organics in Ontario were growing peas and oats together for their dairy which was a very cheap and easy mixture to grow.

Figure 28: peas and oats grown together by Mapleton Organics for their dairy

Christian Abadie in Southern France used to need all his 100ha to feed his 60 dairy cows but now only needs 20ha because he has improved his soil through no-till and companion cropping. He tries to have two if not three crops per year. Next year he is growing maize, sunflower and vetch together as he thinks it will make the perfect ration combination. He is going to use taller varieties of sunflowers so they don't get shaded out by the maize. He also ensiles pea/triticale as a whole crop.

Sarah Singla in the south of France grows lucerne for silage. She plants the lucerne with a companion of beans, vetch and peas. Using this mix gives a better first cut in the spring. She is also going to plant peas and vetch with her winter wheat; take a first cut of silage in the spring then let the wheat grow on.

In Switzerland it used to be traditional to grow vetch/peas and oats as a good forage together.

Case Study: Colin Seis, Australia

I did not go and see Colin as I thought a trip to Australia to see just one man was maybe not the best use of my Scholarship money but I wanted to include him and pasture cropping into my report as I believe it is a great example of intercropping and using diversity. The native pasture grasses in Colin's area are C4 and they have a period of the year when they are dormant. So what Colin does is plant oats into his pasture in the dormant period. As oats are a C3 grass they will grow at different times and conditions to the native C4.

This means the C4 does not compete with the oats and so you get a good oat harvest. Then after the oat harvest the C4 grasses start to grow again. You can also use grazing and/or selective herbicides to help supress the pasture if it is competing.

Colin has pasture cropping in each field about 1 in every 4 years and/or opportunistically. The benefits are that you get a cash crop from your pasture and you don't have to re-seed the pasture. Also the oats bring diversity and energy to the soil system to help rejuvenate the soil and increase carbon sequestration (up to 9t /ha of carbon annually).

Figure 30: **Oats growing on Colin's farm.** ***(photo courtesy of www.arlash.com)***

This leads to better growth of his C4 pasture throughout his rotation. Colin has now developed "multispecies pasture cropping" where he will plant multispecies fodder crops into pasture for feeding the animals. These multispecies crops further improve the soils more than single species cereals.

I saw a similar idea at Gabe Brown's farm in North Dakota where he had taken on some land that had a 12 year old alfalfa ley that was very tired. Instead of replanting the alfalfa he planted rye and vetch directly into the ley. The root exudates of the annuals reinvigorated the soil biology and the production of the alfalfa returned.

Recommendations:

- In terms of pasture cropping I was not sure that it would have much use in the UK. After some thought I think perhaps it does. If you swap around planting C3 grasses into C4s, to planting C4 grasses into C3s then I think there are possibilities. I think it would only work in pastures that contain more native grasses and not necessarily the high production leys as I think they will compete too much. An option would be to plant C4 cereals such as millet into the pasture. This would grow in the heat of the summer when the native grasses are less productive.
- You could plant a summer fodder mix into the pasture with warm season plants. There would be a few things to consider in our climate. Due to almost 12-month growth of grasses in our maritime climate and there not being such a defined dormant period of C3 pastures, you would probably need to employ grazing and/or selective herbicides more to supress the C3 grass.
- Most permanent pastures in the UK have thick thatches of grass residue in the bottom of them. This would need to be reduced by either raking, biological stubble digestion like trichoderma, and/or by planting the crops using strip till which would clear the thatch away from the seed, before you planted a summer crop into them. Otherwise your summer seeds won't stand a chance getting through the thatch.
- Plant a temporary intercrop of fodder species with winter cereals. Either graze the mix over the winter or take an early cut of silage if the weather and ground conditions allow. This would help reduce weeds and disease in the cereal crop.

4.j. Agro-forestry/alley cropping

When I started my Nuffield Farming journey I was determined to avoid Agroforestry for a couple of reasons. Firstly I thought looking at trees would complicate my report and as I am an arable farmer what have trees got to do with arable farming? The second reason was that Stephen Briggs, a fellow UK Nuffield Farming Scholar, has done an excellent report on Agroforestry and I did not want to copy him.

Dr Dwayne Beck came to visit the UK in 2015 and spoke of an interesting theory. When he arrives in a country he looks at the native vegetation and ecosystems to guide him in what type of farming systems would be sustainable in that particular location. Most of the UK would naturally be woodland. After a while I realised if we really do want to be sustainable in our climate here in the UK we really need to include trees as they can bring multiply benefits. Here are some of the benefits of Agroforestry: increased land productivity; yield diversification; better use of resources; reduction in nutrient losses; increasing carbon sequestration and enhanced biodiversity. So here is my short section on Agroforestry - read Stephen's report for more detail!!

Case Study: Stephen Briggs, UK

Stephen farms what seem to be some of the most fertile soils that I have seen: around 23% organic matter, natural release of around 150kg/N/ha per year but, like most soils, they have their inherent problems. (contd on next page)

They are very prone to wind erosion, due to intensive root and vegetable growing they are structure-less and being fertile weeds grow like stink! These problems led Stephen to consider Agroforestry. So six and a half years ago he planted 52ha of his farm into Agroforestry

Figure 31: Stephen Briggs's farm in Cambridgeshire

He has planted 13 different varieties of apples (half heritage), the alleyways are 24m wide and he grows arable crops in between the tree rows. Stephen's whole farm is organic so the trees receive no inputs and the apples go to making juice. Stephen is getting 10% more produce off his farm with agroforestry, a diversity of income, spread of workload, reduced wind erosion, improved nutrient cycling, more beneficial insects (to name just a few benefits). The interesting thing is that Stephen is a tenant. He managed to convince the landlord to allow him to plant trees and think long term. He does, though, have an end date to his lease and so he needed a tree crop that would give fast payback. That is why he chose apples. In an ideal world he would have planted a diverse mix of fruit, nut and timber trees to spread risk of disease and harvesting. It was great to see someone making trees work on arable land.

I am loathe to give recommendations for agroforestry as my knowledge is minimal but I have included a few for starters.

Recommendations:

- You need to remember you need diversity in trees too, so when planning agroforestry try to plant more than one tree species, and in random sequence too. *(continued overleaf)*

- Make sure you have a market for the tree's produce before planting
- Plant trees north to south in the UK to minimise shading
- No more than 25m between alleys, otherwise you start to reduce the benefits
- You need to root-prune trees, especially at the start, using a sub-soiler along the tree row edge. This makes the trees root more deeply and compete less with the annual crop
- The Dehesa system in Spain is probably the largest agroforestry system in Europe where trees are selected for acorn production to feed pigs. A similar system could work in the UK especially for speciality pasture-fed meats
- Use the trees as a pension fund. Walnut trees can be worth a lot of money after 25 years or so of growth. You need to be patient
- Hazel is cut every 5 years and so is a faster return than walnut for timber trees
- Martin Wolfe has suggested developing a wheat variety that is shade tolerant, and plant this variety close to the trees. This is a research area needing more funding.
- 8% of field will be under the trees, so you need to work your costing out on this figure
- If every farm had one field at least under agroforestry then there would be enough work for a contractor to go around maintaining the trees on arable farms: from pruning, harvesting to storage - to keep costs down.

4.k. Permaculture

I am still not sure what the exact definition of permaculture is and I have read about and seen permaculture in various guises. I have read books from Mark Shepard's "Restoration Agriculture" to Sepp Holzer's "Permaculture" and I am still not sure, so I have looked up the meaning and came across this definition:

> *"Permaculture is the conscious design of 'cultivated' ecosystems that have the diversity, stability, and resilience of natural ecosystems. It is a harmonious integration of people into the landscape in such a way that the land grows in richness, productivity and aesthetic beauty." (Washburn)*

I am still not sure what it means! My understanding is that it is a production system based around permanent crops such as trees that involves many different crops including some annual crops and livestock but I could be wrong! I think it is a perfect study for another Nuffield Farming report.

Case Study: Dennis Siroh, Rusinga Island, Kenya

Dennis is encouraging local islanders to take up Permaculture principles in conjunction with the Permaculture Research Institute Kenya. Rusinga's population in the last 20 years has gone from 5,000 to 30,000 people. The trees have been chopped down for growing maize and the lake has been over- fished. This means that the island's soils are disappearing fast and, due to fewer trees, they get less rainfall now. The idea of growing permanent crops is that they will reduce soil erosion, improve the soil and give an income to the smallholders as well as being able to feed themselves. Dennis took us to see Julie, his star student.

Figure 32: Julie, star pupil on Rusinga Island

Julie's plot is 2 years old. From this small half acre plot she feeds her large family and a lot of the village too, it seemed. She only spends 1-2 hours a day working on her plot. The day we saw her she was harvesting moringa, cassava and beans. Moringa tree is an interesting crop. It is a nitrogen fixing tree that produces timber, fodder, the leaves are medicinal (slows down the effects of HIV) and the oils are sold to the cosmetic company LUSH. On the permaculture plots they grow a vast array of crops (lots of intercropping!!) including: papaya, sweet potato, cow pea, pawpaw, maize etc. An interesting example of companion cropping was with bananas and pumpkins.

Figure 33: companion cropping with bananas and pumpkins

Bananas require a lot of moisture and the pumpkins provide shade to conserve the moisture. No artificial inputs are used on any of the plots. It was a really great visit to see how people are feeding themselves, and selling surplus while at the same time regenerating their local environment, all through growing a diversity of crops.

4.I. Forest gardens and no-till gardens

Forest Gardens are probably permaculture but not all permaculture is forest gardening, so it's got its own section in this report. I had never heard of forest gardens until I saw Dr Martin Wolfe and he mentioned Martin Crawford at Dartington in Devon who has a small forest garden with about 500 different species of plants: so diversity on a different scale to modern arable farming. Unfortunately I have not had a chance to go and see Martin's forest garden but I do have his book plus a real curiosity on how they work. I have taken a definition of forest gardens from Martin's book:

> *"A forest garden is a garden modelled on the structure of young natural woodland, utilising plants of direct and indirect benefit to people – often edible plants. It may contain large trees, small trees, shrubs, herbaceous perennials, herbs, annuals, root crops and climbers, all planted in such a way as to maximise positive interactions and minimise negative interactions, with fertility maintained largely or wholly by the plants themselves." (Martin Crawford)*

Figure 34: Martin Crawford's forest garden in Devon. ***Picture courtesy of www.earthways.co.uk***

These gardens seem to be easily maintained and give an all-year-round harvest.

Below is a diagram from Martin's book which explains well the differences between annual cultivation and natural systems:

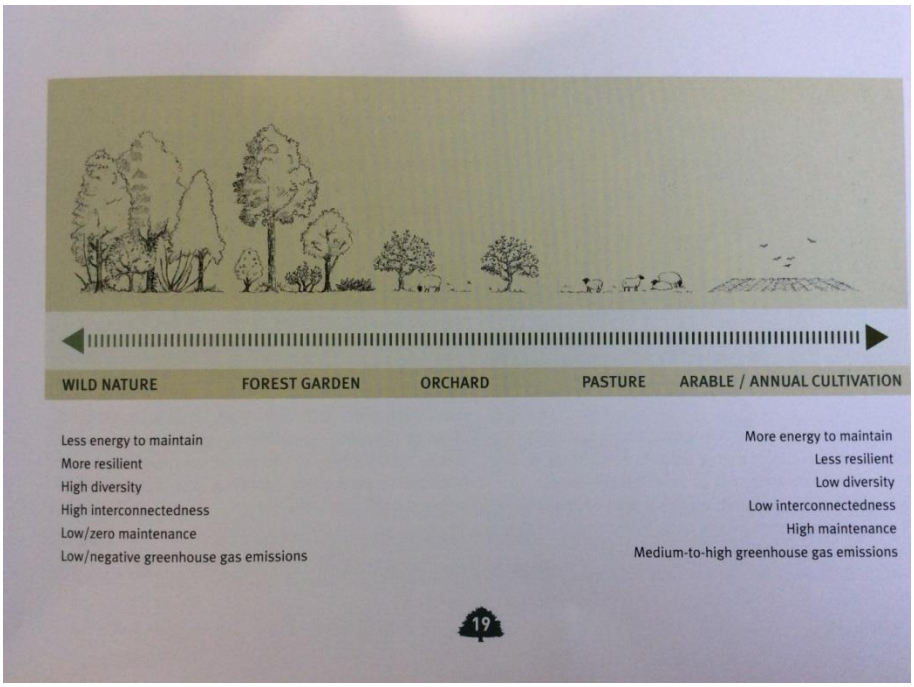

Figure 35: diagram from Martin Crawford's book

More information can be found at www.agroforestry.co.uk . I don't see why this model cannot be utilised on a small area of everybody's farm - or you could have a community forest garden run by a local village for the benefit of the village.

No-till gardens are another great idea that could be carried out on a small area of most arable farms. Gabe Brown in North Dakota planted a small area of one field, which had been no-till for a long time, with over 70 species of plants. There were over 20 species of cover crops, over 30 species of vegetable crops and over 20 species of wild flowers. These were mixed and planted at the same time. The produce from this area he used to feed his family and the surplus was given to charity.

5. A focus on UK main arable crops with intercropping examples and recommendations

I wanted to bring together all the examples of intercropping from the previous section and try to relate this information to the main crops grown on UK arable farms. There will be some overlap but hopefully it will help the reader start to plan intercrops on their own farms.

5.a. Small cereal grains

Winter and spring small grain cereals are the most commonly grown arable crops and, at the moment, very few would be intercropped. This will have to change due to a need to reduce artificial inputs and fight pest resistance. There are many options but I will go through a few I believe have real potential and touch on why some other options are not so viable. First I wanted to show an interesting case study of how to grow cereals in a completely differently way to modern production techniques.

Case Study: The Fukuoka-Bonfils method

This is a method of growing wheat that I had heard about before I started my Scholarship but still to this day I have never seen it tried in the field. Well not yet, I feel another on-farm trial coming on! Marc Bonfils was a French researcher and he took inspiration from Masanobu Fukuoka, a farmer growing rice and other cereals in Japan.

White clover is planted in April. The clover assures better nitrogen fixation, better bacterial life and development of nitrogen-fixing algae in the soil. Then the wheat is planted at the end of June in 60cm rows into the clover. Planting wheat early means it has a long vegetative phase to set deep roots and a longer tillering phase. The deep roots of the wheat also help reduce competition from the clover. Yields of over 15t/ha have been achieved. Below shows some figures of differences between conventionally and Bonfils-grown wheat:

	Conventional	*Bonfils*
Plants per m2	*350*	*1.5-4*
Ears/plant	*0-3*	*100-150*
Earlet/plant	*12-15*	*35*
Grains/ear	*20-30*	*40-60*
Weight of grains	*Low*	*High*

Figure 36: from Agriculturesnetwork.org, How to grow winter wheat? The Fukuoka-Bonfils method

From the table above you can see that the wheat it planted at very low seeding rates. The wheat varieties used need to be older varieties. The variety used must not have any spring wheat genetics. If there are spring wheat genetics then there is a chance that the wheat will produce a seed head before winter due to the early drilling date. *(continued overleaf)*

Modern varieties are hybrids between winter and spring wheat. Older longer straw varieties are needed.

Before the harvest of the first crop of wheat the next crop of wheat is planted into the clover mulch. This is repeated every year. The perennial clover is cut down each season.

Harvesting can be a problem as the next wheat crop is already present, on wide rows, though, and with modern GPS you should be able to avoid damaging the young wheat crop.

Figure 37: Photo by Zoran Petrov. Wheat and clover planted together

With adaptions and trials I could see this method working in UK conditions, though it would have to be very well managed. Utilising it on a large scale could also be difficult. I saw a similar idea with Wolfgang Sturny in Switzerland, where he plants his barley immediately after bean harvest at the beginning of August (100 seeds per m2). The idea is that the barley scavenges the nutrients from the beans and gets a good root system established, then the winter knocks the barley back. Again you would need to look at older varieties and knock back the barley with livestock over winter (as we get fewer frosts. He needs only 80kg/ha of N for 8.5t/ha of winter barley.

To discuss the potential of intercropping for cereals, firstly winter and spring cereals need to be discussed separately, and secondly within these categories high and low input systems need to be separated.

Winter cereals

In winter cereals it is very difficult to get over-yielding from intercropping. This is due to yield being set very early in cereals like wheat, the lack of plasticity/adaptability of cereals when in an intercrop,

and their sensitivity to competition at very specific times in their life cycle. Cereals also compete with themselves so seed rates are a key to success. If you want to grow a high input winter wheat with large inputs of nitrogen fertilisers, then the best options would be primarily variety mixtures. There may not be much of a yield benefit but you should see some disease and grain quality benefits. The second intercrop option for high input winter cereals is to grow a temporary intercrop when planting the wheat. A mixture of legumes, brassicas and grasses should give the plant and soil a good start but choose companion species wisely. Oats make P and K more available through root exudates (5-7kg/ha), also they have potential grass-weed suppression so are a possible species in the mix. Wheat/garlic temporary intercrop in trials reduced aphid attack through volatiles and encouraged ladybird populations. A similar effect was seen by Ma et al in wheat/lucerne intercropping. Winter wheat with 2kg of radish sown at the same time has been shown to have yield increases in USA. The radish sucks up nutrients, not just nitrogen but Bo and Zn and then releases them in the spring when they die. Wheat and mint in India had benefits. This shows the potential for temporary intercropping to reduce insect attack.

Options such as living mulches, full season intercrops and undersown legumes are unlikely to be successful. This is due to the large amount of nitrogen fertilisers used supressing the legumes and making the cereal too competitive. Relay cropping with non-legume species or a cover crop mix is an option as long as the timings and conditions are good. High input systems are likely to have higher herbicide residues which need to be considered when planting an intercrop.

Low input winter cereals have more options for intercropping. Lower or no nitrogen fertiliser additions means that the legume species should survive. This means living mulches, undersown legumes and relay cropping are viable options in this situation. As long as nitrogen inputs are well timed and the legume managed properly. I would recommend you rotate legume species in these systems or, even better, mix legumes to reduce the chance of legume sickness (clover sickness is specific to species).

Finally there is a difference between low input winter cereals and organic winter cereals. In organic where there are no options for herbicide or other pesticides, then a legume full season intercrop could bring big benefits in terms of weed, disease and insect control. Any artificial nitrogen added to the system could see the balance tip in the cereals' direction and the intercrop benefits reduce. Hugh Bulson at Reading University has studied wheat and bean intercropping in organic systems and has seen an LER of 1.27. He studied spring and winter wheat/bean intercrops, which leads me on to spring cereals.

Spring cereals

Priteri et al (2010) showed for organic spring bean/wheat intercrop best results came from a 100% seeding rate of both components giving an LER of 1.44. Hugh Bulson found the best seeding ratios were: 75:75 or 75:50 bean to wheat if you are trying to favour the beans. There was an increase in wheat rust and mildew as bean density increased, and a reduction in chocolate spot when wheat density increased. Beans/wheat are complementary as an intercrop as there is less light competition in the intercrop as they use light in different parts of the canopy and at different times of year. If you use an awned variety of wheat, the awns scrape off the black bean aphid from the beans, giving pest control. Wheat intercrop with faba bean in an additive design increased grain N by 8%. The above examples of spring cereal/legume intercropping show that, for organic farming it has a lot of potential.

The other mixture that seems to have been studied the most is spring barley/pea intercrop. Below I will outline some trial results found for this mixture in organic/ very low input farming:

- barley yields 30% higher if planted 2 weeks before the pea
- Barley/peas – weeds 3 x worse under pea sole crop than intercrop and barley sole crop.
- Barley/peas – 73% of intercrops produced more biomass than sole crops leading to more weed suppression.
- Light not main factor for weed competition but the competition for inorganic N was. An increase of 20% in efficiency of N use in pea/barley.
- Barley can compete with peas through interspecific competition so need to balance your intercrops design to suit your goals.
- Measure N soil supply before planting. The higher the amount of N the lower the amount of peas (a general rule for all cereal/legume intercrop)
- There is not necessarily a benefit of N or yield for subsequent crops as intercrop had used available resources so efficiently, actually some soil N depletion was seen.
- Higher the proportion of pea in previous crop the more benefit for following crop.
- Barley has more plasticity to seed rates and can compensate for lower seed rates
- Positive LER (1.3) in pea/barley is probably not from N complementarity but more from root system dynamics, canopy structure and weed competivity
- Very little nitrogen transfer between pea and barley detected (~6kg/ha/yr.). It has been shown that after 75 days of growth 19% of the barley's N came from the peas
- Adding nitrogen makes barley more competitive
- Indeterminate pea varieties competed more with barley and reduced barley yield (determinate pea maybe better). 22% higher IC grain yield with determinate varieties
- Professor Erik Steen Jensen in Sweden in their cereal/pea intercrops preferred leafed varieties of peas over semi-leafless. This is because the tendrils of the semi-leafless varieties wrapped around the emerging cereal seed head and caused it to emerge poorly.
- Barley cultivars for intercrops must have competitive roots but a canopy that lets enough light through. (Cultivars for monocrop not necessarily the best for intercrop)
- Barley IC gave 85% of sole crop yield and pea was 60% of sole crop (without N), addition of N halved pea yield. LER without N added 1.17 and with N 1.05
- RYT for pea/barley IC of 1.24. Nitrogen addition reduced the RYT due to nitrogen reducing pea yield
- Barley 2-6 times more competitive for soil N than peas
- Nitrogen fixation in the intercrop increased 21%
- Only 35% of fixation in peas was before flowering
- Best seed rate of 45 peas/m2 and 100 barley plants/m2
- Barley grows faster to start with than peas and so competes for more soil nitrogen
- Sowing peas earlier than barley could allow for peas to compete more with barley
- Pea/oat had an LER of 1.38 (oats forced to root deeper as peas root shallow)
- Dr Joelle Fustec found with wheat/pea you can get a 2% increase in wheat protein with a seed rate of 30% wheat and 70% peas. Cracked peas can be a problem while separating intercrop

As can be seen from the above information there has been a lot of research carried out on spring cereal intercropping but, as soon as you add artificial nitrogen, the benefits diminish. The only time you may see some benefit from nitrogen is early in the crop's life cycle if your soil is nitrogen deficient. A little starter fertiliser in cereal/pulse intercropping can be important as it helps establishment, fixes carbon which helps nodulation – positive feedback. Other options of intercropping - such as undersowing - are viable for low input cereals but I don't believe there are many options in high input spring cereals

With any of these mixtures I think you need to decide which of the components you want to be the most successful and manage the intercrop accordingly.

5.b. Oilseed rape

Temporary intercropping/companion cropping with winter OSR is in most cases a no-brainer. The only situation that it may not be appropriate in is if you have a very high broad leaf weed (BLW) pressure and you think by omitting, or if only using a low dose of autumn BLW herbicide, the weeds will swamp your rape. The aim of companion cropping in winter OSR is to remove autumn herbicides, lower N application (20-30kg/N/ha), repel slugs, weevils and flea beetles, improve soil structure and increase yield. A large number of trials have now been carried out and I have listed some of the proven benefits below:

- Mark Hemmant at Agrovista found better establishment of the OSR due, they think, to fewer slugs. Also bigger root-necks on companion cropped rape. He also got a 0.5t/ha yield increase.
- Nicolas Courtois found companion cropping gave the same weed control as pre-em herbicide, 0.11t/ha yield boost and saved 20-30kg/n/ha
- Jaques Charlot has had four years' experience of companion cropping OSR and has got 30kg/n/ha back from the companion, 1 less herbicide used, 2 less insecticides used and 0.5t/ha of extra yield. He also found that the companion competed with the geranium (cranesbill)
- In France they found the best companion crop for cranesbill suppression was camelina and nyger. They didn't reduce numbers of cranesbill but reduced biomass from 285g/m2 to 86g/m2.
- In France companion cropping rape and faba beans together has shown the following benefits: they have root complementarity at the early stages of growth (70% of OSR roots in lower part of the soil and 64% of beans in the top part); dry weight of intercrop was 20% higher; N accumulation in OSR was 30% higher in intercrop but this only happened after flowering of the beans; biological N fixation of the beans was higher in the intercrop; early growth stages of beans uses the large amount of N in the seed so does not compete for soil nitrogen.

Interestingly, though, Dr Joelle Fustec found that the N transfer from rapeseed to beans was the same as beans to rapeseed while they were both alive. Dr Fustec believes that in intercropping the nitrogen benefits come from complementarity of root structures and other factors such as the use of different nitrogen resources.

Below I am going to list some companion species that people I visited were using. There are many possible options.

- Mark Hemmant uses vetch and berseem clover as the clover is deep rooting. There is no point in using berseem clover if you plant OSR in September. He uses common vetch as it is less frost tolerant and does not carry pea and bean soil-borne diseases like red vetch does. He found a bigger benefit when they reduced companion rates down to just 5kg/ha (28 seeds/m2). Perhaps the companions were competing with the rape at higher rates.
- Nicolas Courtois seemed to be using a vast array of species. I have probably omitted some: nyger, buckwheat, forage lentils, red clover, white clover, Alexandria clover, berseem clover, vetches, gesse, spring beans, fenugreek, lucerne
- Soren Ilsoe used crimson clover as an OSR companion
- Benoit Lavier used pea, beans, vetch and lentil as companions.
- NIAB TAG have found that berseem clover, crimson clover, early vetch and Persian clover are the best companions. They were also trialling a brassica mix of linseed, rocket, pak choi and Chinese cabbage. The idea is to dilute the effects of shot-holing; it could also dilute slugs too.

Case Study: Nicolas Courtois, Geneva, Switzerland (Triple Harvest)

I had heard of the triple harvest from an Australian Nuffield Farming Scholar a year before my visit to Switzerland so I was interested in seeing how it works. Nicolas is a researcher for AgriGeneve and carries out many trials. The Triple Harvest has been trialled for a few years. The idea is that immediately after cereal harvest you plant OSR, buckwheat and red clover all together.

Figure 38: OSR, buckwheat and red clover planted all together

You apply no herbicides and then in the first autumn you harvest the buckwheat (see below)

Figure 39: buckwheat harvested in the first autumn

Then the next summer you harvest the OSR and then the same year you harvest the red clover for seed. So you get 3 harvests in one year from one planting. This is a truly brilliant idea. The problem in the UK is that due to our later cereal harvest the buckwheat would not be planted in time to guarantee a crop that year. The mixture would need to be planted in the standing wheat crop. Definitely worth trying the mix though and using the buckwheat just as a companion crop.

There are a few things you need to be aware off when companion cropping WOSR:

- Red clover can interfere with rape harvest so some selective herbicide "calming" may be needed
- There have been issues of lower growth of rape in autumn and delaying of rape flowering
- As said before be careful if the field is dirty with BLW weeds.
- Don't choose companions that are too competitive. There are even differences within species, with some varieties more competitive than others.
- Some recommend drilling the companion crop rape 4-5 days earlier than sole cropped rape, especially on cold clays.
- For weed suppression you want 1800g of green matter going into winter. (1000-1200g of OSR and 600-700g of companion species)

The options for spring oilseed rape is the peola and a multi-species companion that was described in previous chapters.

5.c. Pulses

Pulses are crops where I think intercropping has huge potential, mainly because they are generally low input (especially in terms of fertiliser) and secondly because they have a restricted armoury of pesticides. This lack of pesticides means that in conventional and organic farming you can see some great benefits from intercropping legumes. In the previous section on cereals I suggested that cereal/legume intercrops were not in all cases desirable: legume/cereal intercrops and legume brassica intercrops, though, are viable in many cases. I will explain the difference. In cereal/legume intercrops you are going for cereal yield mainly, and so balancing legume yield without reducing cereal yield is difficult. In a legume/cereal intercrop and a legume/brassica intercrop I would advise that you are aiming for good legume yield and the cereals and brassicas are subsidiary crops which bring certain benefits to the legumes. An example is shown below, which is lentils with oats in Sweden at Joel Mansson's farm:

Figure 40: lentils with oats in Sweden at Joel Mansson's farm

There was a 100% lentil seeds rate with 30-50kg/ha of oats. The oats will act as a trellis for the lentils and help supress weeds by mopping up soil nitrogen. The legume here is the main crop and the oats are subsidiary. This mix I am told can be difficult to separate after harvest.

See Case Study on next page: Professor Erik Steen Jensen and Dr Georg Carlsson, Sweden

Case Study: Professor Erik Steen *Jensen and Dr Georg Carlsson, Sweden*

They were growing many different legume intercrops when I visited and looking at the proportions of each crop, total yield, standing ability, shading and competition with weeds. They preferred leafed varieties of peas in an intercrop as they are less competitive, but they are difficult to find and are lower yielding as a monocrop. This is a good example of where a poorer monocrop variety is better in intercrops than some good sole-cropped varieties. They were trialling lucerne with wheat and faba beans. They found they got better establishment of the lucerne with the mix rather than by itself; the mix was acting as a nurse crop. Another trial was beans/oats and red clover. They are using red clover as they find it is less competitive than lucerne.

They were also *trialling mixed variety stands of beans. In all their trials they were concentrating on the legumes not the cereals. Some of their trials were in conjunction with local farmers where the farmers would give them ideas to trial; a great example of farmer/researcher interaction.*

They told me about a farmer in Germany who was making beer from barley that was intercropped with lentils. He was managing to use the fact the barley was intercropped as a USP for his beer and adding value: an interesting idea.

Below are some interesting facts about legume intercropping:

- Intercropping with legumes is more successful when the legume is forced to rely on atmospheric nitrogen fixation not use the soil available N or bagged N
- In organic bean/wheat intercropping, yields were more stable in intercropping due to lower weed pressure, wheat helped compete with the weeds
- In terms of weeds benefits of intercropping you get the most benefit for the legume rather than the cereal, so if going for improved weed control in cereal then there is not much to gain by intercropping with legume (the legume could make weeds worse)
- The seed rate of barley did not affect its weed suppression ability, so in legume/cereal intercrops you can get away with as little as 5% cereal inclusion. Inclusion of 20% barley reduces weeds by 90% in an intercrop. Martin Wolfe saw benefits with as low as 3% barley inclusion. This is what I would advise to do. Add a very low seed rate of a cereal to a legume for weed reduction and other benefits
- Additive design is better than replacement intercrop design for weeds and also you get an increase of 25% N fixed with lower lodging
- Organic farms have had success with growing yellow trefoil under beans for weed control

No one has given me any evidence on my travels that growing pulses regularly as intercrops or mulches doesn't lead to legume diseases, though there is no evidence it does either. This is probably the most common question I get asked and unfortunately I don't have a definitive answer. I think a few simple rules need to be followed: don't plant legumes consecutively that will carry similar diseases; plant a mixture of legumes, not a monoculture, and diversity will reduce diseases.

5.d. Linseed (flax)

One of the take home messages I got from visiting Colin Rosengren is that, with intercropping, he has made very high risk crops, such as chickpeas, less risky and more profitable. This got me thinking how I could translate this across to our own farm. This year (2016) is our first year of growing spring linseed, which is regarded as a high risk crop, so I wanted to see how I could make linseed less risky and more profitable through intercropping. This spring I have conducted a few on-farm trials to see what may work. The ones that are showing promise are: linseed/buckwheat; linseed/oats and linseed/buckwheat/oats

Below is a picture of the roots of the three-way intercrop in May this year.

Figure 41: the roots of the three way intercrop in May this year

Figure 42: the same crop in July 2016

None of these plots have had any nitrogen fertiliser so it will be interesting to compare yields with our commercial crop.

I have a few observations so far:

- we planted the plots 2 weeks too early and so the buckwheat had poor germination due cold temperatures
- the oats seemed to affect the flowering of the linseed
- the three-way intercrop has had no herbicide, unlike the other 2 plots, but has similar low levels of weeds.

None of these yet have been harvested at the time of writing this Nuffield Farming report so no yield information can be given.

During my travels and research I have found very little on linseed apart from in Canada. Colin Rosengren was growing flax and chickpeas together and the flax was acting as a disease barrier for the chickpeas, and dramatically reducing fungicide needs.

See photo over page

The only reference to linseed intercropping I found in the UK was a study from the 1930s of growing linseed and oats together which is where I got the idea to try it myself. Studies have shown that growing cereals with linseed mopped up spare nitrogen and the crop had fewer weeds. Another study looking at lentils/linseed advised planting the lentils into flax at a 45-degree angle; the angle helped weed suppression. Both were drilled at 75% of a normal seed rate.

Figure 43: flax and chickpeas growing together on Colin Rosegren's farm

Recommendations:

- linseed/oats/buckwheat
- linseed/oats
- linseed/buckwheat
- linseed and lentil

5.e. Maize

Now that maize is an expanding crop in the UK I felt I needed to devote a section to interseeding of maize. The current maize cultivation in the UK is unsustainable and is degrading soils and polluting waterways. Interseeding is one tool which could reduce this damage. There are various benefits to interseeding of maize: undersowing maize with grass can recycle N that would otherwise leach over winter (*Whitmore 2007*); weed suppression; support harvest traffic and so reduce compaction; carbon sequestration and many others.

Case Study: Ed Hanson, Ontario, Canada

Ed was my last visit in North America and I had already seen lots of excellent maize crops, so Ed did well to stand out. There are a few reasons Ed stood out: his maize crops looked excellent and were all no-till (something that I was being told is not possible for maize. Ed puts down his no-till success to early fertility). Also he was using cattle to manage his interseeded crops and maize residue. Ed was interseeding annual ryegrass, red clover and white clover into his maize.

See photo over page

Figure 44: interseeding annual ryegrass, red clover and white clover into maize

He did this as early as possible at the 3-7 leaf timing. He has found a 7bu increase in his maize due to interseeding. After harvest Ed grazes the interseeded crop with cattle: this gives forage for his cattle and also helps recycle the maize residue which can be an issue in no-till. Ed now wants to add companion crops into the row of the maize. The idea is that he should eliminate herbicide usage. The only place he gets weeds are in the row with the corn. He does not use herbicides in his winter wheat now, just high seed rates. Ed was a real ambassador for integrated farming and good soil stewardship, a great last visit.

Interseeding maize is a real win:win situation. Below I have listed some of benefits and mixes people on my travels and researchers have used and found:

- Steve Groff interseeded with radish, triticale and crimson clover
- Loran Steinlage got a 15 bushel/ac yield benefit from interseeding. He has tried clover.
- Iris at U of Manitoba was growing maize with peas, radish and rape. Also vetch and peas in the row with corn and Italian ryegrass in between the rows
- She was also trialling 60-inch rows of maize with alternating rows of flax, radish and soya bean
- Gabe Brown was growing maize and pole beans in separate alternating rows. The “three sisters” without the squash
- Dr D Hooker was interseeding ARG and red clover
- Woody Van Arkel uses orchard grass interseeded with maize as annual ryegrass is a weed worry. Also he is growing a mix of lucerne and clover that he wants to keep as a permanent mulch.
- Dave McEachren interseeded crimson clover, ARG and vetch. He sees a 2-5bu increase in yield

- In Kura clover living mulch with maize there is no response to applied nitrogen but the yield was lower. There is a need to reduce early competition of the mulch.
- When the previous wheat crop is undersown with red clover the maize yield rose 5-12bu in the following crop.
- Nitrogen application rates of 55% in maize after wheat/red clover can give more yield than conventional rates. Problem though is the variable stands of red clover in the wheat. Use of variable N technology to compensate is a possibility.

It seemed to be a common rule of thumb that you plant the interseeded crop at the V6 growth stage of maize (knee high), as maize is sensitive to competition before that growth stage. Weed scientist Dr Rob Gulden said 30 inch rows for maize is stupidity in terms of weed control as too much bare space. Either narrow the rows or add a companion crop to smother the weeds.

Interseeding of maize does not have to be expensive. I saw many examples of homemade machines. Below is Woody Van Arkel's in Ontario:

Figure 45: home made machine for interseeding maize

There are no excuses for farmers in the UK not to be using interseeding. If they don't, I think they could run into some serious environmental legislation.

6. Machinery

Machinery for planting, managing, harvesting and separating intercrops is for me one of the biggest barriers to uptake of intercropping and needs a lot more development. Below I have outlined some of the options I have found. These are not endorsements or recommendations, just an outline of current options.

6.a. Drilling and seeding

Most farms have the equipment to plant a crop into an empty field but many cannot plant an intercrop with many different seeds or a crop into a standing crop. There are options out there outlined below:

Dawn Equipment in Illinois were developing the maize interseeder below when I visited in 2015. There were units going out onto farm at the time.

Figure 46: Dawn Equipment's maize interseeder

The machine planted two rows of intercrop between each maize row. You can vary the width between each unit and vary the depth on each unit. There was the option to apply liquid nitrogen too.

There is now an interseeding service on offer in the UK from Field Options Ltd (www.field-options.co.uk) which is great news and these options need to spread around the maize growing areas in the country.

I saw at Dr Dwayne Beck's in South Dakota the development of clay coated seeds.

See photo on next page

Figure 34: display of different clay coated seeds at Dr Dwayne Beck's

The idea is that the clay coat attracts moisture and gets the seed germinating. It is designed to improve the success of broadcasting seeds. If successful it could make undersowing into a standing crop very easy and cheap. As yet it is an unproven concept. I have tried some clay-coated seed on the farm at home with no success. Even if it germinates you still have the issues of slugs and possible herbicide residues. Watch this space!! Dr Dave Hooker in Ontario found in trials of interseeding maize with ARG and red clover that he only got half the germination from broadcasting instead of drilling. This really shows that in most situations broadcasting is very risky and not good enough, we need a mechanical solution.

Another planter I saw was the WEcoDyn System from Friedrich Wenz, a German farmer.

Figure 48: the WEcoDyn System from Friedrich Wenz. Photo courtesy of Fredrich Wenz

This is a completely modular system and the parts can be moved around the frame. There are three hoppers: two feed into the seed line and one goes onto splash plates which he uses for small seeds. This means he can sow different seeds at the same time; very flexible.

The System Cameleon is a drill I had seen working at John Pawsey's farm in the UK and also at Josef and Joel's in Sweden so I decided to go and visit the factory of the manufacturer. Lars Askling, an organic farmer, had an idea and has gone on to make and develop that idea into the System Cameleon.

Figure 49: the System Cameleon.

It is called the Cameleon as it can be used in many different guises: it is a seed drill, an inter-row hoe and it can inject liquid or solid fertiliser. There are so many different options that the number of different situations you can use it in was mind boggling. In the photo on the next page it is just about to hoe wheat.

It uses a camera to guide in between the rows and has a 25cm side-shift on the frame which is controlled by the camera. You can have three hoppers on the drill so you can plant different seeds and fertiliser at the same time. You can have different seed band width depending on the situation. The coulters easily shift; also so you can change row widths, a truly flexible machine.

Lars was experimenting on his farm with organic farming without the plough. He would grow wheat and then undersow the wheat with rape and grass seed. The second year's harvest was the OSR. Then the grass seed is already there which he harvests for three years and then plants spring beans in between the grass seed rows. The grass seed was mown to keep it down. He left the rows of grass seed to stop weed emerging between the bean rows. This gave Lars six years without ploughing and without herbicides: all made possible due to the System Cameleon.

See photo on next page

Figure 50: the System Cameleon about to hoe wheat

Figure 51: beans sown into mown-off grass seed at Lars Askling's

Garford also have a camera guided inter-row hoe onto which you can add a seed box to plant your undersown crop at the last weeding. See photo on next page.

Figure 52: camera guided inter-row hoe from Garford Machinery

A lot of organic farmers I had met would put a seed-box onto their comb-weeder and possibly roll afterwards to get a good seed-to-soil contact. This is the cheapest option but, from speaking to farmers, it is not always reliable (dependent on rainfall for germination).

Although camera guidance is a great tool for planting undersown crops into a standing crop without damaging the crop, it does have its issues. The main one is that they don't work in twilight very well. One farmer told me you should go home for supper at twilight and come back out when it is dark, as they work fine in the dark. The other issues are when the crop gets tall and/or there is a cross wind blowing then the camera struggles to pick out the rows. This though can be resolved with the use of highly accurate GPS. Both systems can be used, or you could just rely on the GPS, and that would get over the problems mentioned above.

Another concern is in no-till farming. Firstly, no-till farmers would probably resist the idea of inter-row cultivation due to the perceived damage on the soil surface. The other concern would be how would these machines cope with the large amount of residue normally found on no-till fields? There is no definitive answer yet but, speaking to Josef Appell in Sweden, he finds on his no-till crops the inter-row cultivator works well in the spring once the residue has had a chance to decay, but when the residue is fresh in the autumn it can struggle.

Even though most No-till farmers would resist inter-row hoeing I think with the dwindling numbers of herbicides available it may have to become an option. Also, if you are planting an undersown crop at the same time, is it really that bad?

6.b. In-crop

In-crop management of intercrops or undersown crops can be very difficult and requires high precision or a slow speed to avoid damage to the standing cash crop. The easiest way to restrict growth of an undersown crop is to apply a selective herbicide that will damage but not kill the undersown crop, and not harm the main cash crop. This may not be possible if you are organic, if suitable herbicides are not available, or if legislation prevents their use. Stopping an intercrop or undersown crop competing with the main crop can be important to avoid competition and yield loss and also improving nutrient cycling from the undersown crop, so I have outlined possible options below:

An inter-row mower for subduing undersown clover in a corn/ soya bean rotation and for controlling weeds in sorghum was studied by Donald et al. I have not managed to find any images of the mower's design - it seems in the trials they used a strimmer. Jacob Weiner told me inter row mowers have been designed but I am yet to find one. These would work fine in the right conditions and on wide rowed crops like maize. I don't think they would work very well on narrow rowed cereal crops due to design limitations and possible crop damage.

You can use a brush-weeder control growth of undersown crops to reduce competition and increase nutrient cycling. A study by Jacob Weiner: (http://www.jacobweiner.dk/site/Publications_files/Thorsted_et_al_2006a.pdf) has shown increase in grain yield from brushing. Brush-weeders are PTO driven and consist of rapidly rotating nylon brushes.

Figure 53: brush-weeder to control growth of undersown crops. Photo courtesy of www.Baertschi.com

These can be effective at checking growth of undersown crops but are generally slow and energy-intensive machines.

Band spraying of herbicides could be an option especially in conjunction with mechanical methods:

Figure 54: band spraying of herbicides. Photo courtesy of www.microngroup.com

Band sprayers could be used to clean the inter row strip with a non selective herbicide before the planting of an intercrop, in order to subdue an intercrop with a selective herbicide that would otherwise kill the main crop; or to control weeds in the intercrop/undersown crop with a selective herbicide that would otherwise kill the cash crop (for example cereal volunteers/weeds in a cereal main crop). These sprayers would again be limited to wide rowed crops such as OSR and maize.

Like all in-crop machines they rely on the ground being dry enough to travel at the time of needing to use them. On a large scale this could be problematic and I don't think these methods alone can be relied on solely. An integrated strategy is needed.

6.c. Harvesting and separation

In an ideal world the best place to separate an intercrop would be in the combine and to have two or more combine grain tanks that would hold clean and separated intercrops. This though is not available but I am sure it is possible. Professor Erik Steen Jensen was starting a project looking at optical analysis of intercrops coming into the grain tank. There is technology to measure the proportions of each crop coming into the tank. This will allow you to tell the buyer how much of each you have. If for animal feed then the information will help you tailor your ration, and it will allow you to see which parts of the field produced more or less of the intercrop component, which will give agronomic information for following years.

Some intercrops need separating quickly and as soon as after harvest as possible to stop moisture transferring from one intercrop to the other; this is true for peola (peas and OSR). So leaving them mixed in a grain store until the autumn is not necessarily possible. If separation on the combine is not possible then it needs to be carried out between the combine and grain store.

One idea I heard of from Dr Rob Gulden was an intercrop separation trailer. The trailer would have a sieve inside to separate grains, so once you reach the store it is already separated. I, though, have not

found any evidence of such a trailer so far being built. I would imagine it would be similar to a grain dryer trailer, but instead of a dryer have a vibrating sieve.

Figure 55: grain dryer trailer. Photo courtesy of www.agrozaibas.com

The simplest solution to separation is for Central Grain Stores to offer a separation service. They have the equipment to cope with mixed crops. This is what happens in France where most farms are part of Co-Ops and store their grain centrally. They charge around 20 Euros per tonne to separate.

On-farm cleaner/separators can be used. There are various options:

1. Rotary (Trommel) cleaners

Figure 56: Rotary (Trommel) cleaner. Photo courtesy of www.arc2020.eu

The machine above is from Jacques Morineau's farm in France. From what I have been told, rotary cleaners do not always get the seeds clean enough**.**

2. **Gravity separator** like that outlined in the case study below on Colin Rosengren's farm.

3. **Gyratory Reciprocating motion cleaners** such as from Rotex. See below.

Figure 57: Gyratory Reciprocating motion cleaner. Photo courtesy of www.rotex.com

4. **Spiral separators:** see photo on next page.

I am sure I have missed off some options as there are many. The best separation equipment would probably depend on what you were planning on separating. A simple separation of wheat and beans could be carried out with a rotary cleaner, but for more similar sizes seed crops and when you are separating more than two seed types, then optical separators would probably be best.

See *Case Study: Colin Rosengren, Canada, 2 pages further on*

After photo of spiral separator.

Figure 58: Spiral separator. Photo courtesy of www.seedprocessing.nl

Case Study: Colin Rosengren, Canada

Colin could have been a case study under many of the headings in this report as he has a lot of on-farm experience and is one of the few farmers I met who was intercropping on a large scale. He farms 5000ac of which he intercrops 2500ac. To manage to cope with this large volume of intercrops he has his separation system perfected. Colin uses an old Flaman 54" screen cleaner which he has bought and modified.

Figure 35: converted old Flaman 54" screen cleaner

The separator can separate up to 4 different crops and can cope with up to 70t/hr of crop. Colin has the separator on the back of an old lorry which is drives into the middle of his circle of grain bins.

He then augers the grain-cart trailers into the separator, then these huge augers take the separated crop into their own bin, simple!

Not only has Colin perfected his separation set up, he has also been involved in developing a new grain drill with Clean Seed Capital. Colin had a huge 18m drill in his shed but I was not allowed to take photos so I have taken one off the internet from Rocky Mountain Equipment.

See photos on next page

Figure 60: Colin's grain bins and augers

Figure 61: grain drill courtesy of Rocky Mountain Equipment

This drill gives the precision of a maize seeder in a drill. You can apply six different products at once which could include different seeds and fertilisers. You can employ variable rate applications for all the different products. So you can alter the composition of an intercrop as you go across the field. This is all controlled by Bluetooth.

This drill gives Colin the ability of fine tuning his intercrop stands depending on field conditions. For example, in a canola/pea/lentil intercrop he will put a higher seed rate of lentils on the hilltops and then, in the bottom ground, he will increase the amount of peas as they do better there. The next level of intercropping!

Precision farming techniques such as variable seed rates, robots, precision sprayers etc. will make intercropping management easier. For machinery companies to develop machinery for intercropping they need to see a market for these machines and a demand from farmers. This is unlikely to happen on a large scale soon, as monoculture cropping dominates.

This means we as farmers need to develop machines ourselves like Colin Rosengren and Lars Askling have (farmers are not most inventive people I know).

The other option is for universities to develop such machines using grant funds from state. There are some great PhD or Masters projects that could be carried out from the above suggestions. Let us hope it happens!

7. Conclusions

I have given recommendations throughout my report and discussed in detail the pros and cons or intercropping, so I don't just want to repeat everything previously said. So I have produced a list of considerations for a farmer before he enters the field to plant an intercrop, and some things I think need to be done to expand intercropping.

7.a. Things to consider before starting Intercropping, how to plan intercrop

- Is there a market for the produce? There is no point growing a low input, high yielding IC if you can't sell it.
- Crop prices. Make sure if you are growing a mix of crops to harvest that the total income is likely to be greater than corresponding sole crops.
- Soil fertility and soil nitrate levels. These need to be known before planting. The higher the amount of available nitrogen in your soil the higher proportion of non-legumes needed in the intercrop. (Seed rates are critical to success)
- Crop rotation: make sure the intercrop does not affect your following crops e.g. legume sickness or uncontrollable volunteers
- Tillage system: no-till is preferred due to fewer weeds emerging after planting. If you are using tillage make sure you can mechanically deal with weeds as herbicides may not be available
- Field weed pressure: will the intercrop lead to worsened particular weed issues if herbicides are not available?
- Choose which intercrop component you want to dominate and which to be the subsidiary. It is better to focus on one component, e.g. in pea/canola IC it can be better to focus on peas
- Drilling depths and crop row widths. Do the crop mixes require different seeding depths and differing row spacing?
- Mixed or alternate rows? Mixed rows are better in most cases. You get better root and canopy interaction. I only came across one example of separate rows being an advantage which was in flax/chickpea, where the rows of flax acted as a physical barrier to chickpea diseases
- Drilling timings – can the crops be planted at the same time or need different planting times?
- Choice of cultivars – Colin Rosengren chooses varieties by maturity and height, and not yield
- Choose crop species or cultivars which favour the development of beneficial soil micro-organisms, so stimulating plant growth by way of different mechanisms: i.e. enhanced nutrient acquisition, protection against pathogens and modulation of phytohormone synthesis such as AMF or plant promoting rhizobacteria (PGPR)
- Are there any disease or insect pest concerns that may be improved or worsened by intercropping?
- Harvest dates: if harvesting together, will they be ready at similar times? It has been shown that crops mature differently in intercrops and harvest closer together than when they are sole cropped.

- Can your intercrops be separated after harvest? There is a risk of chipping, contamination and staining if the mix is unsuitable
- Quality requirements: fodder, grazing or for human consumption?

7.b. Future direction of research

- Plant breeding needs to take into account weed competition, adaptive capacity, Nutrient Use Efficiency. Current varieties may simply not be good enough for intercropping.
- There should be farmer owned, run and financed breeding programmes for plants cultivars and ICs that they want.
- Problem is most research on Intercropping in the UK has been carried out in organic farming. More research needed in conventional farming.
- A lot of pesticide applications could technically be illegal with current label restrictions. There is a need to re-design the registration system to include intercrops
- Levy boards and state funded research should concentrate on farmers' needs not suppliers' desires. (INRA in France has two low input wheat varieties)
- Benefits of intercropping needs to be demonstrated throughout the supply chain. Marketing of mixed cultivars is difficult which could be solved if buyers understood the benefits

7.c. General

- Intercropping in itself is no magic bullet and, to be successful, needs to be looked at as part of a whole farm-scape design. Design of the whole farm-scape needs to consider not only the total amount of suitable habitats within landscapes but also the spatial arrangements of habitats as herbivorous pests and their natural enemies vary in their capacity for dispersal
- Do not concentrate solely on the nitrogen benefits of Intercropping. It is much more complex than just N

8. Last thoughts

Throughout history there have been empires and civilisation that have crumbled and failed partly due to their failure to look after their soils. The Roman, Greek and Egyptian empires declined along with their soils and the evidence can still be seen today in Europe and North Africa. You would have thought in the information age, where at the touch of a button we can access all this information and history, that we would be avoiding the mistakes of the past. This unfortunately does not seem to be the case.

On my travels I saw how North America is rapidly eroding its soils through vast expanses of monoculture and this is within the living memory of the Dustbowl. Also I saw on Rusinga Island in Kenya how the local population had degraded the island's forests and soils rapidly in only 30 years. You don't need to travel abroad to see the same things happening in the UK. The rapid expansion of maize growing in the UK is one practice that is having devastating effects on our own little island. So what should we be doing about it?

The latest folly to be banded in the agricultural media is that we should be pushing yields higher and harvesting 20t/ha of wheat. I presume this will be achieved through applying 300, 400 or even 500kg/ha of nitrogen fertiliser? Applying 5, 6, 7 or maybe 8 fungicides throughout the season? Use hybrid seeds that need high inputs? I am sure an academic can show us a graph of how far we can push up yields using the above methods.

The graph that won't be shown is the graph showing declining soil carbon and fertility through high use of nitrogen fertilisers. This push will decimate our soils and give all the farmer's hard earned income directly to the suppliers, leaving the same extremely tight margins we have now when producing 10t/ha of wheat, but with worsened soil health. This is before I even talk about weed, disease and insect resistance that we won't be able to control and which will occur through the above methods. We are struggling to make a living at 10t/ha, our soils are already degraded, weeds, disease and pests are already becoming beyond our control. Why do we think doing more of the same thing is going to have a different outcome?

I suggest as farmers we change the way we farm; let us bring the control of our own farms back on farm. It can be done! I have met pioneers around the world who are doing exactly this. How are they doing it? By mimicking mother nature and increasing DIVERSITY on their farms. I suggest our goal for the future should be to produce around 20t/ha of produce from our land each year, but differently. Instead of producing vast tonnages of high input monoculture, let us produce low input intercrops followed by undersown/relay crops, or even undersown forage crops to produce forage for animals. This can be down in the shade of alley crops producing trees for fruit, nuts and timber, while poultry forage around in stubbles and under the trees.

Why can't every farm have an acre or two of forest garden and a no-till garden? All off the same hectare of land we can produce a diversified array of products in one year with reduced external input, while at the same time rejuvenating our soils. This is the future of farming, led by farmers. Now let us get on with it!

9. After my study tour

I have learnt so much through my Nuffield Farming Scholarship that it is difficult to know where to start in terms of using the ideas on our home farm. Unfortunately we only have one growing season per year which limits the amount of on-farm trials that can be done. This is why I believe farmer-to-farmer and farmer-to-researcher cooperation is critical (to speed up time taken, and trial many different things in one year).

What I do know is that the home farm will have to change and intercropping is going to be a key element to these changes. I have already started by carrying out trials this spring with further trials organised this autumn. My long-term goal is to have every crop intercropped in some form every year.

A medium term goal is to halve my input costs by 50% in 5 years (I only have 4 years left now). Long term I hope to emulate farmers like Gabe Brown and reduce my input costs by over 90%, while maintaining farm output and improving profitability. These are big targets that I have set myself but I will achieve them. This will be with the help of other farmers, my new network of farmer friends around the world, and like-minded experts. Watch this space!

I would also like, after my Nuffield Farming Scholarship, to help other farmers achieve such goals. I have been fortunate to learn so much in the last 2 years; now it is time to pass on this knowledge.

10. Executive Summary

The age of high input/ high output agriculture is coming to an end. The rise of weed, disease and insect pest resistance to agricultural chemicals is contributing to this demise, as high input farming drives the resistance to these problems it is trying to solve.

The other reason high input farming is coming to an end is because the over-use of tillage and artificial fertilisers in these systems had led to our soils being degraded, eroded and the overall fertility reduced. We need to find farming systems that can produce plentiful outputs without the plentiful inputs. Intercropping is one tool that will help us transition to low input farming. It is not a new tool - there is evidence of intercropping from 5000 years ago - it is a forgotten tool. My great-grandfather would be more familiar with the concepts in my report than more recent generations.

The aim of my Scholarship was to explore what intercropping had to offer UK arable farming and what ideas could work in the UK. To find answers to these questions I travelled to the USA, Canada, France, Switzerland, Germany, Kenya, South Africa, Sweden, Denmark and the UK. This mix of countries visited gave me an insight into highly industrialised farming, low input farming in the developing world, and visiting Europe and the UK gave me examples of intercropping in similar climates to our own. I discovered on my travels more ideas and intercropping options than I ever thought were possible. There are so many different options that I believe there is no farm in the UK that would not benefit from some type of intercropping, though is not a magic bullet. It is a practice that needs to be very well planned and managed to avoid any potential problems. There needs to be careful thought before ordering any seed, let alone planting it. Intercropping is a knowledge and management intensive practice, not input intensive. On average intercropping seems to give a 20-30% increase in output; there are not many techniques that can achieve such gains.

I found on my study trip that there is a lack of on-farm research into intercropping. This needs to increase to realise its full potential and for the practice to expand. I believe the research needs to be funded by and carried out by farmers, levy boards and governments. We cannot rely on agri-chemical companies to fund and develop research in this field as there is little opportunity for patents or profits.

The development of specific machinery for certain intercropping systems is needed for these systems to be successful. There needs to be machinery development at all stages of growing intercrops from seeding, weeding, through to harvest and separation. I think modern engineering can solve any machinery issues found in intercropping; it just needs funding.

The overall conclusion from my study is that intercropping has HUGE potential for the UK and the rest of the world.

Andrew Howard

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Appendix 1 : Terminology in alpha sequence

ALLEOPATHY:	alleopathic plants are species with the ability to produce chemical compounds which negatively influence the growth and development of weeds, pests or diseases (*Weston 1996*). Rye, sorghum and sunflower plants inhibit weed germination. Brassicas reduce weed germination, pests and diseases through the decomposition of their residues
CHEMICAL EFFECT:	changes in the chemistry of the biosphere caused by a component of an intercrop to positively or negatively affect other species i.e. root exudates increasing nutrient availability or causing alleopathy.
COMPETITION (INTERFERENCE):	the process in which two individual plants or two populations of plants interact such that at least one exerts a negative effect on the other (*Vandermeer*). Competition is not as simple as described above; competition can lead to positive feedback if both crops are well established.
COMPLEMENTARITY:	when species differences give rise to a better overall use of resources in intercrops than in separate sole crops (*Vandermeer 1989*) The diagram below outlines some ways species can facilitate and complement each other: *(see diagram at end of this Appendix)*
DILUTION EFFECT:	increase biodiversity and species richness in a particular spatial locality is protective against disease/pest spread, due to less of the population being susceptible to the disease/pest compared to a population of genetically similar species - where all are susceptible.
FACILITATION:	the process in which two individual plants or two populations of plants interact in such a way that at least one exerts a positive effect on the other. Double facilitation is equivalent to mutualism. (*Vandermeer 1989*)
INTERSPECIFIC COMPETITION:	the competition effect of one species on another species
INTRASPECIFIC COMPETITION:	the competition effect of a species on plants of the same species **SPARING EFFECT:** where legumes fix atmospheric nitrogen and so reduce competition for soil Nitrogen (N) with non-legumes
OVER-YIELDING:	the amount a species yields when grown with other species compared to yield in a monoculture. Most common reason for over-yielding is when crop mixtures exhibit temporal complementarity. In Canada in conventional agriculture you got over-yielding 75% of the time in intercropping, and in organic it was 47% of the time.

PHYSICAL BARRIER EFFECT:	a species of an intercrop creating an obstruction to a disease vector, pest or weed of the other intercrop component(s), so reducing/slowing down the spread of disease, pest or weed
REPLACEMENT AND ADDITIVE INTERCROP DESIGN:	this is a question of plant population and seed rate. In a replacement design, mixtures are formed by replacing a given number of one component by the same number of the other component. As a result the relative density of each component is less than when grown in a pure stand, but the total stand density is the same. In additive design mixtures are formed by adding plants of one component to the other component at the same rate as in their pure stand, so the total density of the stand is higher. The ideal is likely to be somewhere in between the two designs.

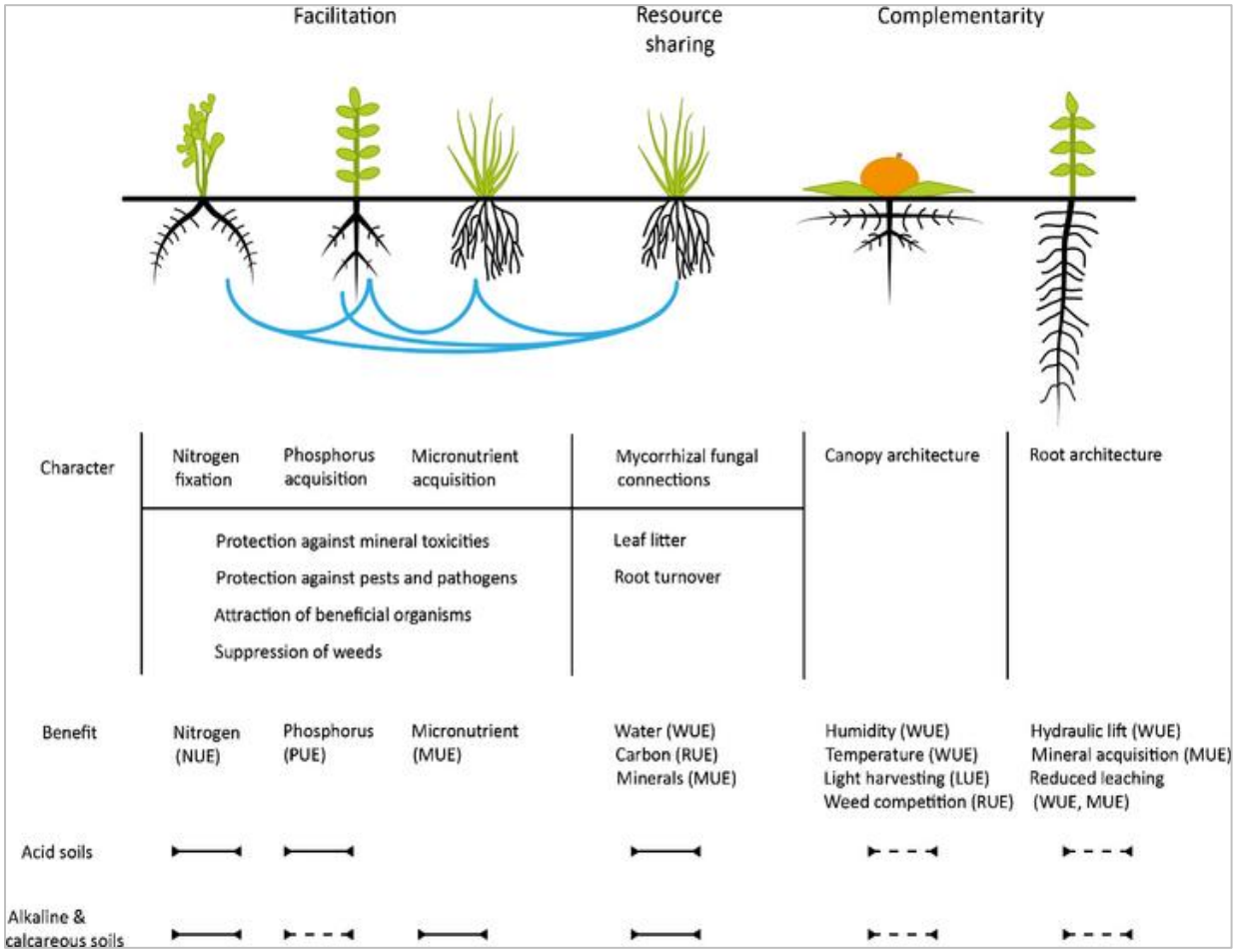

Figure 36: some ways species can facilitate and complement each other. (Courtesy of Brooker et al)