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RESEARCH TOPIC REVIEW: Non-Inversion Organic Arable Cropping

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1. Scope and Objectives of the Research Topic Review:

"Seven years were required for me to break away from conventional ways of thinking of soil….Then I discovered that the trouble lay in the operation which preceded all of the tests, namely in ploughing" Edward Faulkener Ploughman's Folly

The phrase "Non-Inversion Tillage" (NI) as used in this review first requires definition. Any system which does not seek to substantially invert the soil profile is regarded as NI. The mouldboard plough is widely used as the primary tillage tool and through the disturbance of the soil profile can be regarded as the antithesis of non-inversion tillage. For the purposes of this review literature that refers to minimum, conservation, and reduced tillage and also direct drilling techniques have been consulted these phrases are all non inversion approaches to cultivation. However there is a range of tillage equipment that can be used in a NI system and these would include discs, chisel ploughs (or cultivators), rotary tillers or machines that combine some of these elements within a single pass. These different pieces of tillage equipment have different attributes and benefits but no distinction is made between these different techniques.

NI has a number of perceived advantages over ploughing and several perceived disadvantages. The advantages include:

- N nutrient losses are reduced
- Cheaper crop establishment through lower energy use
- Improved Soil Organic Matter levels
- Sediment runoff and so P & K pollution is reduced
- Wind erosion is reduced
- Better soil structure more resilient to compaction

The perceived disadvantages include:

- Greater weed burdens
- Lower yields
- Lack of tilth for seed establishment with direct drilling

The advantages in terms of soil conservation and improvement have made NI a more relevant option in much of North and South America and Australia where, in areas, soil erosion is a significant problem.

In Europe and particularly the UK where soil losses are typically less severe and the cost of pollution from sediment and nutrient loss is not of immediate financial loss to the farmer the adoption of NI has been less and the more traditional approach to cultivation of ploughing has remained dominant.

The objective of this literature review is to ascertain the likely benefits and possible challenges inherent in moving away from inversion tillage.

2. Summary of Research Projects and the Results

Munkholm Lars J.; Schjonning, Per and Passmussen Karl J. (2001) Non- inversion tillage effects on soil mechanical properties of a humid sandy loam. ***Soil and Tillage Research*** **62 (1-2):pp 1-14 (Organic)**

This research compared soil mechanical behaviour under a conventional tillage system using a mouldboard plough and a NI system using a subsoiler and combination drill establishment system. It concluded that the quality of tilth achieved under the NI system was not as good as that achieved through a conventional approach. However these assessments were made in within the early stage of changing from a conventional to NI system and it was acknowledged that the longer-term benefits of NI may be greater and they also acknowledged that the NI system removed an existing plough pan.

ADLib Glossary (Non-organic)

www.adlib.ac.uk/ema/content.aspx

Carbid beetles are understood to be a major predator of slugs and NI is shown to have a less harmful impact on populations than ploughing. They are a useful bio-indicator of impacts of soil cultivation.

Minimum cultivation may reduce broad leaf weeds but grass may require special attention. Blackgrass (Galium aparine) and Brome (Bromus sterilis) may increase as it is virtually entirely removed by ploughing.

Ozpinar Sakine (2006) Effects of tillage sytems on weed population and economics for winter wheat production under the Mediterranean dryland conditions. ***Soil and Tillage*** **Research 87 (2006) 1-8 (Non-organic)**

Ozpinar undertook work to investigate the effect of different tillage systems on winter wheat yield, weed density and tillage economy on a clay loam soil in Mediterranean climate in Northern Turkey. The treatments used were mouldboard plough (CT) and rototiller (RT) and discs (DT). Findings showed that RT gave the highest returns because although yields were not highest establishment costs were reduced. DT has lower costs but also lower yields due to higher weed burdens and so does not perform as weed economically. Finally CT gave best weed control and average yields but was the most expensive system to use and so did not perform as well economically as the RT system.

S.P. Cuttle, C.J.A. Macleod, D.R. Chadwick, D. Scholefield & P. M. Haygarth (IGER) P. Newell-Price, D. Harris, M.A. Shepherd, B.J. Chambers & R. Humphrey (ADAS) (*January 2007)* An inventory of Methods to Control Diffuse Water Pollution From Agriculture. *Defra Project ES0203* (Non-organic)

Defra estimate that on clay loam soils making use of manure applications (most organic systems) there will be a reduction in the loss of both N and P of approximately 6.8% and and 4% respectively if a Conversion Tillage (CT) system is adopted. The same work estimates that this combined with a reduction in machinery costs will save costs of £40 per ha**.**

Project Ecological Soil Management (POB) (Organic) www.soel.de/english/poeb_ueber_e.html

This project is taking a longer term view of soil quality under organic systems. One of the treatments used as part of this project was a non-inversion tillage cultivating to 30 cm depth. The study concluded that the non-inversion tillage system led to higher humus content in the upper soil crumb and increased microbiological activity, higher earthworm population and higher levels of water infiltration. However lower yields were experienced due to higher weed incidence. (This paper was a translated synopsis of the published work from this project, in German).

SAC Technical Note 580 Crop Protection in Reduced Tillage Systems (Non-organic)

This paper reports on SEERAD funded work looking at weed and disease incidence under min-til systems in Scotland.

Both Annual Meadowgrass (Poa annua) and Chickweed (Stellaria media) was a significantly greater problem under a min-til treatment whilst volunteer OSR , Forget-Me-Not (Myostis arvensis) and Field Pansy (Viola arvensis) numbers were eliminated under a stale seedbed technique. This Annual meadow Grass infestation led to a 60% groundcover in March following drilling in autumn 2001. Grass seed and volunteer cereals establish better in the soil surface than do broad leafed weeds and so in a non inversion system grasses tend to germinate more readily. Allowing germination followed by a seed bed cultivation will help reduce the grass weed burden.

Disease incidence was also recorded. Take All and Eyespot and were shown to have lower incidence on average under a min-til system whilst Fusarium levels were higher. This is because being soil borne Fusarium is not removed from the growing crop by burial as is the case when using a mouldboard plough. A similar difficulty occurs with ergot. Ploughing puts the fruiting bodies underground where they will not re-infect the subsequent crop.

W Bond & RJ Turner (2005) Review of tillage and Weed control. HDRA <u>www.organicweeds.org.uk</u> Defra Project OF0315 (Organic)

This work is primarily focussing on weed control strategies and the role tillage can play. The following findings are reported from a number of publications reviewed the by the HDRA staff. References for these papers are shown in the paper.

- Reduced tillage gives better control of soil erosion, conservation of soil moisture and more efficient use of fossil fuel

- Finer seedbeds produce more weed seedlings and allow better opportunities for direct weed control through cultivation.

- Rougher seedbeds allow few weeds to germinate and give weeds more protection against direct weeding operations.

- Non-inversion tillage keeps fresh weed seeds near the surface where shallow cultivations. Under chisel plough regime 30% of weed seeds in the top 1 cm of soil. In reviewed work over a 7 year period the distribution of weed seeds in the soil profile changed dramatically. Under a no-til and non-inversion regime 74% and 61% of weed seeds were in the top 5cm of soil whilst under a mouldboard ploughing system just 37% were present.

- Timing of cultivations also has an impact. Weeds such as black grass and wild oats have a greater germination earlier in the season and delaying planting can help reduce weed numbers in the following crop as well as providing opportunities to operate a stale seedbed system.

- Understanding weed germination requirements can help determine drilling dates and weed emergence characteristics. Mean seedbed temperature is important in determining the number of seedlings that emerge the week after cultivation. Temperature would be affected by soil moisture as well as air temperature and daylength.

The Ploughman's Folly by Edward H Faulkener

In his book Edward Faulkener argues the value of the mouldboard plough remains unproven and that its predominance as a tillage tool is due as much to the acceptance by farmers of the use of a mouldboard plough than any more compelling argument. He further suggests that the inversion of soil has several negative effects upon the soil.

- it breaks the natural capillary action of the soil leading to greater likelihood of drought stress of the seedling plant.
- Lower organic matter levels on the surface layer of the soil result in greater run-off of rainfall contributing to lower soil water levels but also greater risk of soil erosion.
- it places decomposition products beyond the reach of the developing plant and the organic matter at the plough depth draws water to it including water from above thereby reducing the water available to plants in the horizon above the organic matter layer.
- it creates a condition for decomposition which is starved of air. The decomposition generates carbon dioxide which being heavier than oxygen fills the soil matrix with Carbon Dioxide displacing the air upwards. This has two effects. It reduces the air available to the plant roots and the soil flora and fauna that are integral to process of breaking down soil organic matter and making nutrients available plant roots and most importantly deters saprophytic nitrogen gathering bacteria (free living nitrogen fixing bacteria).

Faulkener further develops this theme by choosing examples from natural systems to illustrate that the most fertile ecosystems are those that suffer little or no inversion of the soil such as forests or natural grasslands and that these systems allow the regeneration of new plants through minimal disturbance of the soil. Arguing that the fertility was generated though the decomposition of leaf mould and or animal faeces which was then easily available to developing seedling.

Evidence is given using reports of experiments he conducted and personal experiences of agricultural systems using simple hand planting equipment that did not invert soil.

One experiment was conducted using tomato plants. A rye crop was disced in to incorporate and the ground prepared by exerting a small amount of pressure at each point the tomato plant was to be located so re-establish the capillary action of the soil damaged by the discing. Each plant was then planted simply, " the roots of each plant after being freed of all clinging soil, were laid in the prepared track, covered with as mellow earth as could be found nearby, and firmed in place by tramping." The plants were left flat on the ground. The reported crop yielded well, better than other conventionally established crops.

Clements R *et al* (2001) Clover: cereal bi-cropping for organic farms Defra Project OF 0173 (Organic)

Looking at bi-cropping as a means of reducing weed burden in the growing crop and supplying nitrogen to a growing crop this project investigated the potential for the establishment of cereal crops into a growing white clover crop. The clover was controlled prior to drilling by either mowing or rotovating. Despite the perceived advantages of such a a system this work concluded that without herbicide control of the clover the crops did not establish and develop sufficiently because of the competition to the crop created by the clover. However the work did note that better results were achieved using oats and triticale crops rather than wheat due to the greater competitiveness of these crops and that more success may have been achieved if a more numerous cultivation passes had been used to give better clover/weed control prior to establishment of the crop.

Holland J.M (2002) The Environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. ***Agricultural Ecosystems & Environment*** **103 (2004) 1-25 (Non-organic)**

Conservation Tillage (CT) reduces soil erosion and pollution through run-off by between 15% and 89% and so nutrient and pesticide pollution such that fertiliser application rates can be reduced leading to a reduction in P loading in run-off of 24%. Further where CT is practiced streams support greater levels of insect life.

The type of cultivation used also under a CT system also effects run-off rates with sediment loss reported at 532, 828 and 1152 kg/ha respectively under no-till, chisel plough and disc plough respectively

Producing crops using CT uses less energy and causes less wear and tear on parts and is estimated to save 23.8kg C/ha per annum (this is US work). Another study put this figure at 26.8 kg C/ha for a maize Zea mays) soyabean (Glycine max) rotation. Further work looked at the total energy use for CT and plough based systems over 6 years under two different systems and concluded that the CT systems used 16% and 26% less energy than the plough based equivalents. Given the lower N and P leaching rates and potential to reduce fertiliser applications CT could have a greater impact upon reducing energy use.

CT however may require additional cultivation operations to assist with weed control. However the table below indicates the relative energy use of different operations and even additional energy used in further cultivations will be less than that used for ploughing. Approximately 8 passes with a cultivator can be undertaken for the same energy used in a single ploughing operation.

Energy used in Agricultural husbandy operations		
Operation		**kW energy per ha**
Mouldboard Plough		175
Sub soiler		163
Drill		35
Spring Tined Cultivator		21
Disc		42
Power Harrow		115
Combine Harvester		125
Leake, A R ., 2000. Climate Change, farming systems and soil. Aspects Appl. Biol. 62, 253 - 260		

The cultivation of soil releases soil carbon into the atmosphere and reduces soil carbon by reducing soil organic matter (SOM). Studies in the UK indicate that soil carbon was 8% higher than under conventional tillage systems and work in Scandinavia showed it to be 25% higher in the top 5cm of soil and 20% higher in the top 30 cm of soil. However the time taken to see such differences will depend upon the amount of organic matter returned to the soil and the intensity of cultivation.

The benefits of the change in SOM build up in the soil surface layers are rapidly lost if ploughing is used.

SOM levels are closely linked to soil biodiversity with cultivated soils having lower biodiversity than uncultivated ones with CT somewhere between the extemes. Soil biodiversity comprises Microorganisms, mesoffauna and Macrofauna and the impacts of CT are different on these three different groups and different species within these groups and other factors such as input use will also have a bearing .

Microbial biomass, diversity and activity is generally higher in systems using CT techniques than in those using deep cultivations. These microbes are more concentrated in the soil surface layer whilst under a plough system crop residues are more evenly distributed through the soil profile and so changes in the microbes present and their roles and efficacy in nutrient cycling is different.

Nematode species are susceptible to soil cultivation as they rely on soil moisture for movement. They are believed to be responsible for up to 30% of soil mineralisation. In the short term when using CT plant parasitic nematodes may increase as they are no longer being destroyed by ploughing

However other nematode species important in nutrient cycling will benefit but the lack of information about which species are most important in nutrient cycling and how their numbers might be enhanced makes understanding of this difficult.

For the Mesofauna there are also inconsistent findings. Work investigating Collembola and Acari populations (which are important in nutrient cycling under systems making use of organic manures) show variable results with Collembola showing increases in number under no tillage systems and a decrease under shallow tillage regimes. However there was a greater concentration of these populations at the soil surface in the 0 – 3 cm profile.

Work indicated that where soil structure is degraded this resulted in a reduction of microfauna and Collembola numbers because of the reliance of these on pore space.

For macrofauna species are affected by tillage regime. Eathworm populations are effected. Inversion tillage has a negative impact as earthworms are than exposed to desiccation and predaction. CT nearly always results in an increase in earthworm numbers. When studied over a 10 year period it was shown to be 36% higher under CT than mouldboard ploughing system. In dryer Mediterranean climate the increase was even more significant.

Species such as Isopods (woodlice), Myriapods (centipedes) and Gastropods (snails) are sensitive to soil cultivation but are encouraged by CT as organic matter is available on the surface and physical structure of the soil surface encourages movement and so aids their dispersal. Slugs are often reported as becoming problematic following a move to CT. As they are not as sensitive to cultivation as other gastropods their numbers can rise rapidly due to the availability of organic matter on the soil surface.

Inversion of soil not only physically destroys marcofauna but also has an indirect impact as food sources, in the form of green matter and other organic matter are likely to be removed. The timing of operations can also be important as species may be more vulnerable during different life stages. Carabidae beetles are less vulnerable as they have shown themselves to be tolerant of cultivation and their ability to disperse quickly allows them to escape.

The overall number of macrofauna present may not be effected by a switch from mouldboard ploughing to CT but the abundance of species present may be effected.

For birds and vertebrates the abundance of seed at the soil surface and the availability of mesofauna generally encourage these species

CT can have an effect of flora with a greater selection towards perennial species with reports that both Sterile Broom (Bromus sterilis) and Blackgrass (Galium aparine) increased whilst Field Poppy (Papaver rhoeas) remained low.

3. Analysis and Conclusions

The opportunities for using an NI approach in organic systems has not been well investigated by research and what research has been done has not perhaps been sufficiently long term. The benefits of the system in terms of the economics of establishment and the improvement in soil quality make the system attractive but it is a system that will take some time to get established and is one that will require the farmer to “hold his nerve” as grass weed, perennial weed burdens and slug predation may increase in the early years of implementation. In conventional systems and the POB work yields have reported to drop when implementing an NI system. This is before some of the benefits of a better quality soil are seen, but in the work done by Dr Michael Brandt in an organic system no yield drop was experienced and this too was the case for Danish work done by Per Schonning.
Phosphate (P) and Nitrate (N) losses can be reduced as soil structure improves and becomes more stable. Better water ingress into the soil will reduce run-off and sediment and P loss and better water retention in the soil structure will reduce leaching potential. This is perhaps particularly the case at the time that the ley phase of a rotation is broken when greatest risks of N leaching occurs particularly if this coincides with significant rainfall.

The organic matter left at the surface is likely to result in a rougher seedbed which not only helps preserve soil crumb structure but provided the soil is not overworked can help reduce capping on prone soils.

Soil moisture for germination is improved as the soil capillary remains intact and therefore germination draws from deeper soil moisture reserves rather than surface soil moisture. Given changing and uncertain rainfall patterns over recent seasons and forecast greater extremes in weather patterns for the future the ability of soils to help buffer climatic conditions will be increasingly useful.

It is difficult to quantify the economics because of the range of farm systems employed but if compared in terms of energy consumption, (which will also indirectly compare machinery costs). It can be seen that from Table 1 that a lower cost of establishment is achieved by avoiding ploughing if this cost is equated to fuel use. However, this does not take into account labour costs as a two pass system using a plough/press and combination drill is cheaper in labour than several repeated passes with a NI cultivator even if one of these is used to drill the crop as in the case of Yatesbury Organic Farm (see Appendix 1).

The evidence would seem to suggest that whilst weed burdens may not increase there is likely to be selection towards more grass weeds and perennial weeds. Greater opportunities to control weeds will develop as the weed seed bank will be held towards the upper layers of the soil which has several benefits. Firstly, the weeds are likely to be easier to germinate following harvest and control through mechanical means, they are more accessible to surface predation by birds and finally the historic seedbank is no longer disturbed and brought to the surface to germinate.

To help overcome some of the weed problems that may occur:

- drill cereals later to allow better use of stale seed beds and particularly to reduce germination of Blackgrass (Galium aparine) and wild oats (Avena fatua*)*
- keep seed beds coarser to reduce germination of weeds
- make best use of undersowing and crop canopy to help the crop outcompete weeds as they germinate

Stale seedbed techniques for weed control will have an impact on nutrient loss from a soil and the level of weed burden that can be accepted without having a significant yield reduction must be understood and weeding operations based on this understanding. For example with grass weed species Blackgrass (Galium aparine) will have an impact on yield at a relatively low population density perhaps just 2 plants per m2 whilst for Annual Meadowgrass (Poa annua) a population of 50 plants per m2 will be required to have a similar yield reduction.

It is possible that both slug and nematode predation will increase. This is likely to be a temporary effect. Both species will be provided with more suitable conditions for population expansion whilst others who might fill a similar ecological niche are not present. However over time these species which will compete with slugs for example woodlice for soil surface organic matter will increase and compete with slugs. Similarly with harmful nematodes, once other nematode species and mesofauna populations increase the effect will be to reduce the impact of harmful nematodes.

To reduce possible pest burdens:

- allow maximum exposure to predators. *Carabidae sp.* are one of the major predators of slugs and so ensure field margins encourage their lifecycle and allow for access to larger field areas through the use of beetle banks to provide access to a greater area of the crop.

Soil type and timeliness of operation are likely to have an impact upon the adoption of the system. It is often felt that NI systems suit a narrow band of medium textured soils. They are used across a broader range of soil types in other parts of the world and have been adapted successfully. On heavier soils when soil temperature at establishment is more critical the idea of delaying drilling to achieve a suitable seedbed and to reduce grass weed germination may be unwelcome. However, higher workrates for chisel plough type cultivators may allow greater opportunities for cultivations to be done in a timely manner. The lower power requirements for this type of operation may also encourage farmers to make less use of contractors which again might help improve timeliness.

The only work reviewed, Clements *et al*, looking at using green manures as a means of weed control prior to establishing the crop did not achieve much success however the potential of such a system to reduce potential weed burden when using a non inversion system seems to have merit. Perhaps more experimentation is required using other less competitive cover crops, or even less competitive varieties of clovers and the involvement of the Claydon company (with their Direct Drilling philosophy) in the ongoing Wheatlink (Sustainable Link Project LK 0970) project may lead to advances in the development of this technique.

As with much in organic farming the opportunities to try innovative approaches exist and will be undertaken by the engaged and innovative farmer seeking to develop their system. The development in NI has been is better understood in the conventional context where it has gone hand in hand with a herbicide regime. It must be prudent to look at the experiences of the conventional system and learn from these and adapt them to the organic scenario than disregard them and as more farmers convert who have experience and expertise in NI in the conventional setting this can be used to develop the system for wider adoption within the organic sector.

During the IOTA Arable Research Workshop held on 15th November 2008 (Appendix 2. R&D priorities) a number of research and development needs were identified, which will be important for the wider commercial application of non-inversion tillage in organic farming.

4. References

Munkholm Lars J.; Schjonning, Per and Passmussen Karl J. (2001) Non- inversion tillage effects on soil mechanical properties of a humid sandy loam. *Soil and Tillage Research* 62 (1-2):pp 1-14 (Organic)

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SAC Technical Note 580 Crop Protection in Reduced Tillage Systems (Non-organic)

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5. Appendix 1

Case Study: Yatesbury Organic Farm

Farmer: Richard Gantlett

Prior to the start of conversion in 1998 Richard had been experimenting with non-inversion cultivation on the 300 ha of cereals at Yatesbury Farm. The burning of stubble made incorporation of stubbles relatively easy without ploughing but the a belief in the importance of soil structure and the role that straw residues could contribute lead to experimentation on one area with non-inversion techniques even when straw incorporation was required. This experimentation led to a system whereby ploughing was only used intermittently. There was little understanding of soil biology at this time.

Following organic conversion ploughing was gradually reintroduced to the farm as the perceived wisdom was that ploughing is an important weed control technique.

However a growing appreciation for the importance of soil biology gave Richard the determination to make a non inversion system work and a meeting with Alex Podolinski and later with Manfred and Frederick Wenz on their farm in Germany gave him the confidence to develop a system that dispenses with ploughing.

The cultivation routine seeks to break up the soil surface at a very shallow depth causing minimal disturbance to the soil but providing sufficient horizontal slicing of the soil surface to destroy fertility building ley, volunteers and weeds with an aim to allow the soil to weather and break down along the natural fissures and weaknesses in the soil thereby leaving the soil flora and fauna as undisturbed as possible to allow them to maintain greatest efficiency.

Originally a Horsch cultivator with a wide duck-foot share was used. Each duck-foot is approximately 37 cm wide and they are set 30 cm apart. The angle of the share has been altered slightly to give a flatter pass through the soil and the initial pass is made at a very shallow depth of just 2 cm(max).

Alongside this use of cultivators the soil’s natural fissures and breaking points are seen as important in the development of the tilth. Care is taken therefore not to overwork the soil to roll or “chop” the soil which might result in a too friable soil that would be prone to capping and consolidation in wet weather. Any such capping inhibits crop growth and allows weeds such as couch and docks to establish.

Figure 1 Horsch Terrano cultivator

More recently a similarly configured, though with a smaller duck-foot share Lemkin Thorit chisel tine cultivator has been used for the initial cultivation with the Horsch used mainly for drilling. The Lemkin provides a different action, mixing the soil and plant residue better with closer tine spacing and more curved tine action.

As part of the cultivation routine a "C" tine ripper is used to lift and aerate the soil and alleviate compaction at a depth of approximately 15-40 cm depending upon the circumstances. Interestingly in Germany where this approach was developed no ripping is undertaken but they are working on a smaller scale with much smaller tractors.

Cultivations are carried out at approximately 1-2 week intervals in order to allow weed flushes to develop and be destroyed by cultivating.

Following (usually) 3 passes the drilling is undertaken. The Horsch cultivator with a seeder fitted on the front linkage and a coulter behind each tine with a deflector plate set below each coulter to spread the seed to mimic broadcast seed distribution. When set up to drill a finger tine is used behind the Horsch to complete the covering of the seed. The seed is not rolled to improve soil/seed contact instead the capillary action of the soil draws moisture from below due to the drying created by cultivation and this initiates sprouting. By placing the seed into the right place in warm moist soil (it has not been inverted and cold soil exposed) it is believed establishment is enhanced and the crop begins growing before the weeds have an opportunity to re-establish themselves.

When initially developing this approach, there were concerns that the weed burden would increase. However the approach of keeping seed in the surface layer and allowing them to germinate and then removing by cultivation has been largely successful. Certain weeds are present but at levels which are not considered significantly detrimental to yield

The cultivation regime described is equally applicable to the destruction of the ley phase of the rotation as to the establishment during the cereal rotation. For ley destruction cultivations are started in July and order to give time to kill the ley. The proportion of grasses in the ley mixture has been reduced to retain a reasonably open sward which is not too densely matted and grasses are more difficult to control with cultivations alone. In addition a broad range of both legumes and herbs are used in order to have a greater range of rooting profiles to assist the physical structure of the soil. Different species will also establish preferentially in different part of the field. Red clover is used within the mix and despite its use in every cycle of fertility building there is no apparent build up of sclerotinia perhaps because the plant is thinly planted within the mixture.

Manures are applied to the leys and allowed to break down to be incorporated by the living soil. Sometimes manures are applied to green manures and incorporated as the green manure is incorporated.

6. Appendix 2 R&D priorities drawn from the IOTA Arable Research Review Workshop

In the course of the IOTA arable workshop the following comments/observations were recorded:

- *A better understanding of soil biology and the impact of low/no till practices upon it are required;*
- *Information on the potential for very shallow ploughing as well as non-inversion is needed;*
- *Long term monitoring of these techniques is required;*
- *Weed kill issues and the impact of these techniques on weed levels is needed;*

Additional papers from Dr Charles 'Merf' Merfield:

http://www.merfield.com/research/crimper-rollers-one-route-to-organic-no-till-farming.html

http://www.merfield.com/research/initial-trials-of-a-crimper-roller-in-new-zealand.pdf