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|  | **Measurement** | **Method/protocol outline** | **Data variates analysed and current levels** | **Target for Sustainable vs Conventional** | **Goal for management** |
| 1 | Soil chemistry | 1 kg soil collected to 20 cm depth from every GPS location (60/field) across all fields in March every year. KCl extract on fresh soil for NO3 & NH4; acetic acid extractions on oven dried samples for K, Ca, Mg & P; Elemental Analyser for %C and %N; loss on ignition at 450 ⁰C and 900 ⁰C; pH by CaCl2 and H2O; | Total N (0.2% c, 0.24% s), NO3 (208.9 c, 170.8 s), Total C (1.6% c, 2.04% s), pH (5.44 c, 5.56 s), NH4 (12.32 c, 8.0 s),Ca (2073 c, 2386 s), K (127.1 c, 251.6 s), Mg (212.9 c, 222.5 s), P (65.82 c, 67.08 s): units mg kg-1 dry soil.  (mean values for spring crops, March 2013) | Target SNS index of 3, equivalent to 110 kg N ha-1 (convert kg ha-1 to mg kg-1 assuming 26 kg soil ha-1 to 20 cm depth; target index of 2 for P (16-25 mg kg-1) and K (121-180 mg kg-1 fresh soil), pH 6.5 (Defra Fertiliser Manual (RB209) 2011), SOC critical threshold of 2% (Dungait et al, 2013) | Maintain target SNS index, increase K index, replace mineral fertiliser with renewable sources (crop residues, BNF, organic product inputs), increase pH (liming & compost), maintain/increase soil carbon to >2% (compost addition and straw incorporation) |
| 2 | Soil biophysics | 36 paired soil core and bulk soil samples from all fields in June of year 1 and 6 of each rotation. Samples analysed for volumetric water content, dry bulk density, air filled volume, penetrometer resistance and root elongation assay as in Valentine *et al.* 2012. Shear vane measurements (4 reps) taken at all 60 locations per field in March. | Soil cores are stored awaiting processing. Shear vane measurements are reported in the text. | Shear vane measurements give an indicator of soil strength and therefore resistance to root growth. Specific targets not set, but the sustainable treatment should show statistically significant reductions in soil strength relative to the conventional cropping system. | Increases in soil organic matter through compost addition, stubble incorporation and margin recycling should lower resistance to root growth, mitigating the increase in resistance associated with non-inversion tillage. |
| 3 | Soil Water Quality | Ceramic cup lysimeters installed adjacent to the GHG cover boxes in beans, winter wheat and spring barley fields (10 locations per field). Samples collected alongside gas samples. Tubes evacuated to 60 KPa for 24 hours. Samples KCl extracted and analysed using Konelab Aqua 20 Discrete Analyser for total N, NO2, NO3, NH4 | Total N for 2013. Wide ranges in the data reflect seasonal fluctuations.    Beans: 5.5%, range 22.9 (s); 8.1% range 42 (c)  Spring barley: 38.8%, range 177 (s); 37.6%, range 182 (c) | Target: decline in %N under sustainable treatment; significantly lower levels relative to conventional management. Data will be used in a total N audit for each field using an extended version of the simulation model in Young et al 2011. | Cover cropping, reduced mineral N inputs, crop varieties with enhanced nutrient use efficiency traits as part of the CSC will be assessed in terms of reductions in the rate of N leaching. |
| 4 | Run-off and erosion | See Dungait *et al* 2013 and Lewis et al 2013 for two completed erosion studies at the site. Funding required for follow-up work and for work on run-off. | 137Cs measured from 60 locations across K field in 2011 gave an estimated max rate of 1.2 t ha-1 yr-1  Run-off measurements to be funded. | Statistically significant reduction in soil erosion between treatments by end of first rotation, 50% reduction by 2022 (end of second rotation). Run-off targets to be set. | Tied ridging, sown tramlines and spiked harrow/low pressure tyres to mitigate erosion. Recycling margin vegetation to reduce losses in run-off from 2015. |
| 5 | Greenhouse gases | GHG emissions measured at 10 points/field in beans and winter wheat and 50 points/field in spring barley. Samples collected every 28 days from sowing to harvest using static chambers sealed for 60 minutes. Gas samples analysed for CH4, CO2 and N2O by gas chromatography using high purity standards. Funded through EU FP7 Legume Futures to compare legume/non-legume and winter/spring crops. | CH4:range -15 to 30 CH4-C g ha-1d-1 (winter av -10, growing season av 12 g ha-1d-1)  CO2: range -10 to 90 CO2-C kg ha-1d-1 (winter av -7, growing season av 40 kg ha-1d-1)  N2O: range 0 to 85 N2O-N g ha-1d-1 (av 20 g ha-1d-1)  (example data are from winter wheat 2012) | From HGCA Guide 57 2012, Scottish Government targets: 1.3MtCO2e reduction by 2020 from 2008 levels, equating to a 15% decline.  Target maximum averages by the end of the second rotation should therefore be < 85% of current levels. | Cover cropping, non-inversion tillage, direct drilling, precision fertiliser placement should be tested for emission reduction potential and incorporated into the sustainable cropping system where possible. |
| 6 | Biological Nitrogen Fixation | Atmospheric derived N (Ndfa), % 15N and total N are determined in legume (L) and non-legume (NL) plants at pod fill and harvest from 60 locations per field. 15N natural abundance method is applied to dried samples using the standard measuring protocol of Nykänen et al., (2011). Ndfa in the legume is calculated as - (δ15N NL - δ15N L) / (δ15N NL - B) where B is the reference 15N abundance of the legume grown with only atmospheric N2. | Dry weight, N15 and total N measurements indicate that N fixation of up to 200 kg ha-1 yr-1 by field beans. Circa 80% of fixed N was removed at final harvest, but up to 50 kg N ha-1 was left in the senescent shoots and nodulated roots. | Target >100 kg ha-1 yr-1 residual fixed N over the 6 course rotation: 50 kg from field beans and 50 kg from clover. | Maximise N supply from BNF through the rotation: field beans, clover and other legume species. Reduce losses through run-off, leaching and volatilisation by cover cropping, reduced soil disturbance and margin buffers. Investigate alternative complementary understorey species and intercropping options to increase the BNF potential through the rotation. |
| 7 | Crop development | Crop cover, growth stage and height recorded at all 60 GPS locations in every field at monthly intervals through each growing season. | Growth stage, height and % cover of weed and crop from emergence to maturity | Target: no difference between treatments | Higher seed rates to compensate for poorer establishment in non-inversion till, improved weed competition. |
| 8 | Biomass | All weed and crop plants are harvested from 0.5 x 1 m quadrats at 36 locations in each field at crop maturity (within 2 weeks of harvest). Monocot and dicot weeds, crop stems and grain dried, weighed, milled and processed through the Elemental Analyser for %C and %N determination. | Dry weight and % C and % N m-2 for monocot weeds, dicot weeds, crop stems and grain.  Data to be used as part of nitrogen audit simulations and weed-crop competition studies. | Target: no difference between treatments in crop parameters; greater dicot weed biomass and less monocot weed mass under sustainable management. Crop:weed biomass regression with a shallower negative slope . | Data to be used as covariates for yield, N audits and other analyses – no specific management requirements other than herbicide treatment (see 14-16 below) |
| 9 | Yield & Quality | Final yields are collected off the combine for each variety strip (5 or 6) per half field. Yield quality is measured annually on samples collected from 60 x 1m2 quadrats per field at harvest. MS, ICP and EA analysis for C, H, N, protein, amino acids, broad scale metabolomics, dry matter, potato tuber defects, sugars, carotenoid content, vitamins, amino acids, micronutrients, thousand grain weight, % moisture, hardness, starch dry matter, alcohol yield, minerals, phenolics. | Total yield (2013 data in t ha-1 N.B. seasonal fluctuations are high so data is illustrative only and should not be used to assume trends until after full statistical analysis and publication at the end of the first rotation):  Potato 46 (s), 47 (c); Winter wheat 8.1 (s), 10.7 (c); Spring barley 6.8 (s), 6.8 (c); Beans 4.6 (s), 5 (c); Winter barley 8.8 (s), 10.2 (c); Winter oilseed 1.6 (s), 3.9 (c) | Target: no difference in total yield or yield quality of crops grown under the sustainable cropping system relative to the conventional system.  Target yields to match national averages (www.scotland.gov.uk): Potato 45, Winter wheat 7.5, Spring barley 5.8, Beans 3.5, Winter barley 6.6, Winter oilseed 3.3 2013 data in t ha-1) | Maintain yields of cereals and potatoes at lower levels of non-renewable inputs, through improved soil fertility and alternative sources of plant nutrients (e.g. BNF). |
| 10 | Crop pests and diseases | Barley disease incidence is scored (following HGCA RL protocols) in winter and spring barley in May, June and July at all 60 GPS locations per field | Pest and disease incidence (% infestation on a scale 1-9) | Target Is for disease incidence to show no significant difference between cropping systems. | No specific management as yet, though IPDM programmes will be incorporated for the 2nd rotation. |
| 11 | Soil borne potato pathogens | Seed and progeny tuber sampling and bulk soil taken as a combined 'W' sample per treatment in all fields in March (pre-planting) and November (post-harvest). *Spongospora subterranea*, *Rhizoctonia solani*, *Helminthosporium solani* and *Colletotricum coccodes* assessed in seed and progeny tubers and soil (Brierley et al 2014). | Disease incidence assessed as spore balls per g soil or pg DNA per g soil for each organism.  *S. subterranean* (0-4.3 spore balls g-1)  *R. solani* (0-226.3 pg DNA g-1)  *H. solani* (no spores/DNA detected 2011-2013)  *C. coccodes* (0-204 pg DNA g-1) | Target s for disease incidence to be no greater under the sustainable cropping system than the conventional cropping system. | No specific management as yet, though IPDM programmes will be explored for incorporation from the 2nd rotation. Currently, disease incidence and spread is monitored. |
| 12 | Soil microbial diversity | 60 bulk soil samples collected to 20 cm depth in all fields in March every year (360 samples in total per year). Soil sieved to 2mm and sub-samples stored at -80⁰C for DNA extraction. | Samples stored for future analysis – funding required. | Microbial activity expected to be greater under sustainable management. Implications for nutrient cycling to be tested through regression modelling. | Compost addition, straw incorporation and reduce soil disturbance expected to stimulate microbial activity in the soil. |
| 13 | Weed seedbank | 60 x 1 kg bulk soil samples collected to 20 cm depth in all fields in March (360 samples per year). Soil sieved to 10 mm and seeds germinated in seed trays under standard glasshouse conditions (light intensity 300µmol.m2.sec-1; 12 hour day length; 18oC min day temp; 15oC min night temp; shade screens operative at 600µmol.m2.sec-1 set and 22oC). Numbers of emerged seedlings per species recorded until no further emergence. Soil then re-sieved and the process repeated for a 2nd flush. | Number of seeds/ species/ location calculated per m2 to a depth of 20 cm.  2011-2013: 33 species recorded, average of 3500 seeds m-2 (range approx. 1000-4000 m-2), composition approx. 80:20 monocot:dicot.  Full dataset is required for statistical analysis, available at the end of the first rotation. | Measured seedbank densities are roughly half the densities found in a survey of commercial arable fields throughout the east of Scotland using similar sampling and germination methods (Hawes *et al* 2010). Here, densities were roughly 8000 m-2 (conventional) and 17,000 m-2 (organic).  Increase the density and diversity of dicot weed seeds, and decrease the proportion of monocots to a max density of 8000 m-2 | Herbicide regime to target monocot weeds and allow some reseeding of uncompetitive dicot species. |
| 14 | Emerged weeds, and  Weed biomass | % cover and number of plants/species in 0.5m2 quadrat at 60 locations per field in spring (May) mid-season (Jun) and before harvest (Aug).  Dry weight, %C and %N of above ground dicot and monocot weed biomass from 36 x 1 m2 quadrats per field (see 8). | Winter crops 0-20% weed cover, both treatments (higher end for WW, lower for WOSR and WB). Spring crops: no weeds in conventional potato, up to 20% cover in sust potato; up to 25% in conv beans and sp barley; up to 100% in sust beans and sp barley. | Target: low weed cover (<10%) in winter crops and potato; 10-20% cover to support arable foodwebs in spring barley and beans. Max control of grass weeds, allow some reseeding of dicot weeds (see seedbank). | Herbicide regime to target monocot weeds and allow some reseeding of uncompetitive dicot species. Investigate options for varying timing of application to achieve target. |
| 16 | Litter decomposition rates | Standardised protocol for simple measurement of decomposition using tea bags (Keuskamp et al. 2013) buried at each of the 360 sample points in April and left for 90 days before cleaning, drying and re-weighing. | Higher decomposition rates have been detected in the sustainable field halves where soil organic matter content is higher, but this protocol has only been pilot tested in the first rotation so full datasets are not yet available. | Target: higher litter decomposition rates in sustainable soils where disturbance is lower and organic matter higher thereby support a more diverse and abundant microbial community. | Organic matter inputs from compost and straw incorporation. |
| 17 | Earthworms | At 120 of the GPS sample locations, earthworms are collected from 50 cm2 soil samples in April at the same time the litter decomposition bags are buried. Adults are identified to species and juveniles are counted. | This protocol is under development and will be included as a new indicator set during the second crop rotation from 2017/8. | Expected trend is for higher earthworm number in the sustainable system. Differences between functional groups will be tested | As above. |
| 18 | Surface invertebrates | 168 pitfall traps are set across the platform (14 in each half field) in margins and cropped area in mid-April for 2 x 2 week trapping periods. Carabids are identified to species, all other insects are recorded to order or family. Sampling protocol adapted from Brooks *et al.* 2003 | Number of insects in main groups (Collembola, Aranneae, Staphylinidae, and Carabidae species) per trap/half field. Preliminary analysis suggests greater carabid numbers in sustainable broadleaved crops and fewer numbers in sustainable cereal crops relative to conventional. | Pitfall trapping is a relative measure of activity-abundance patterns so specific density targets cannot be set. Target is therefore is for greater population and activity levels under sustainable relative to conventional management. | Species rich margins, and diverse dicot within-field weed flora to provide resource to support viable insect populations. |
| 19 | Epigeal invertebrates | 144 vortis suction samples of insects from the weed and crop vegetation are taken across the platform (12 from cropped area, 12 from margin vegetation per field) in May, June and July each year. Sampling protocol is adapted from Haughton *et al.* 2003. Invertebrates are identified to order and the numbers of insects are recorded. | Numbers of all insect groups converted to number per m2. QA checks required on data before analysis. Correlations between broad trophic groups in each crop/treatment will be used to assess management impact. Method following Hawes *et al* 2003, Hawes *et al* 2009. | Target: greater densities of all invertebrate groups under sustainable management, where weed resources are more abundant and diverse, relative to conventional. Separate studies required to determine critical thresholds for plant biomass to support viable insect populations. | Species rich margins, and diverse dicot within-field weed flora to provide resource to support arable foodwebs, particularly populations of natural enemies. |
| 20 | Pollinators | 72 x 50 m pollinator transects are walked (3 along margins and 3 into the cropped area per half field) once a month from May to August. Walks are carried out between 10.00h and 17.30h ideally when temperature is above 13oC with at least 60% clear sky, and above 17oC in any sky conditions, apart from heavy rain. | Number of all foraging honey and bumble bee colour types are recorded within 2 m of the transect and butterfly numbers per species recorded within 5 m of transect. Data to be QA checked before preliminary analysis | Target: more pollinator counts in sustainable field halves and margins. Further work is required to determine critical limits for pollination of crop and weed species. | Species rich margins, and a weed management programme to encourage a diverse dicot within-field weed flora, aiming to provide a continuous resource pollen/nectar supply during main activity periods. |
| 21 | Margin vegetation | Margins around the sustainable field halves will be sown in 2015 with a wildflower species mix designed to support pollinators and insect natural enemies. Areas will also be sown with seed mixes designed to trap nutrients otherwise lost in run-off from the field. | Percentage cover of all plant species and flowering frequency will be monitored from sowing onwards. | Target: continuous supply of nectar and pollen resources for insect pollinators and natural enemies. Separate study required to determine critical thresholds to maintain viable insect populations. | Margins to be sown in spring 2015 and maintained with an annual cut from establishment. |
| 23 | Farm operations | Detailed records are kept of all input costs (fuel, seed, agrochemicals, compost), the machinery and methods used, tractor time, and the timings of all field operations. These are recorded for calculations of costs, gross margins and carbon footprint | Cultivation (type, depth, fuel used, time, date)  Sowing (date, seed rate, varieties, time, fuel)  Fertiliser (type, rate, fuel, time taken, date)  Crop protection (target, type, AI, rate, time taken, fuel used, date)  Harvest (machinery, time, fuel, date, sale price).  Example calculations of carbon footprint from this data are given in Figure 4. Gross margins are calculated from ∑(sale prices)-(input costs) over the full rotation. | Data are used for calculations of overall environmental and economic costs and benefits, as well as covariates in other analyses. Single targets cannot be set, but overall, the costs should be no more for sustainable than conventional practice. A Dexi modelling approach (adapted from Pelzer *et al.* 2012) will be applied to this data to assess overall performance of the two cropping systems. | Integrated management to maintain resource supply (BNF, organic amendments, tillage practice) and regulate pest and disease incidence (natural enemies, crop variety mixtures, threshold pesticide applications) at lower rates of agrochemical inputs. Target: limit production costs and increase profit margins by reducing losses and increasing efficiency to maintain yields |