Integrated Pest Management (IPM) – Weeds

The James Hutton Institute UK

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Weeds[1] are among the major pests[2] of the world, taking from crops and contaminating harvests. Control, whether mechanical or chemical, is expensive and polluting. Weeds are also wild plants, integral to the ecosystem. They have beneficial roles, mopping up nutrients and supporting the farmland food web, which itself contains organisms effective in biocontrol and pollination.

Weeds and crops have cohabited since agriculture began here 6000-5000 years ago. Many of the weeds have been crops or forages, while most crops give rise to volunteer and feral weeds.

The Institute has been studying weeds for over 20 years. Capability in maintained through development of methods[3], infrastructure[4], field platforms[5] and site networks[6] in Scotland and throughout Europe[7].

The main aim of work on *IPM- weeds* is to understand and manage the weed flora so as to optimise the several roles of weeds without reliance on chemical pesticides. This document summarises established capability and new topics.

Contents

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[1] Weed: a general term defined here as wild plants that grow with crops, and which may be harmful, neutral or beneficial to agriculture.

[2] Pest: "Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products" (ISPM No5, International Standards for Phytosanitary Terms 2010; FAO, 1990, revised FAO, 1995; IPPC, 1997)

[3] Standard methods of field sampling, seedbank analysis and statistical design augmented with techniques including N-fixation by 15N natural abundance method and elemental composition.

[4] Including dedicated laboratories and glasshouse suites for phenotyping.

[5] The Institute's farms at Dundee and Glensaugh, notably the long term Centre for Sustainable Cropping (CSC) at Balruddery Farm Dundee.

[6] The Maritime Study Region in the lowland, arable areas of Scotland

[7] Through EU-funded projects – SIGMEA, Legume Futures, PURE and AMIGA

Established research areas

The science in IPM-Weeds seeks to optimise weed populations, not just by targeting weeds directly by mechanical or chemical means, but by manipulating the system through factors such as crop variety, crop sequence and soil tillage.

Each research area contains a short introduction, names to contact, current and previous funders and a sample of refereed publications, showing most recent first then some earlier papers that helped establish the topic.

Managing weeds - the seedbank as indicator of farming intensity

Weeds of arable land and grassland are sustained by a seedbank[8]. The seedbank decays through predation and disease and is replenished by new seed dropped by reproducing plants. Through these processes, the seedbank changes in abundance, species composition and life history traits. Because only a small percentage of the seedbank germinates in any year, its composition is a good accumulator of the recent history of field management and a guide to how a field should be managed to optimise the various roles of weeds. The ideal is a moderate seedbank from 2000–8000 m^{-2} consisting of a balance of 20 to 40 species, not dominated by any type such as annual grass weeds.

Contact: Geoff Squire (geoff.squire@hutton.ac.uk), Cathy Hawes. Current work: SG SRP[9] 2011-16 Land Use Theme; Centre for Sustainable Cropping at Balruddery[10]; PhD projects. Previous funding: SG 2006-11[11], BBSRC LINK, Defra, crop levy boards.

Lewis, T.D., Rowan, J.S., Hawes, C., McKenzie, B.M. 2013. Assessing the significance of soil erosion for arable weed seedbank diversity in agro-ecosystems *Progress in Physical Geography* 37, 622-641

Begg, G.S., Wishart, J., Young, M.W., Squire, G.R. & Iannetta, P.P.M. 2012. Genetic structure among arable populations of *Capsella bursa-pastoris* is linked to functional traits and in-field conditions. *Ecography* 35, 446-457.

Hawes, C., Squire, G.R., Hallett, P.D., Watson, C.A. & Young, M.W. 2010. Arable plant communities as indicators of farming practice. *Agriculture, Ecosystems and Environment* 138, 17-26.

Hawes C., Begg G.S., Squire G.R., Iannetta P.M. 2005. Individuals as the basic unit in studies of ecosystem function: functional diversity in Capsella (shepherd's purse). *Oikos* 109, 521-534.

Squire GR, Brooks DR, Bohan DA, Champion GT, Daniels RE, Haughton AJ, Hawes C, Heard MS, Hill MO, May MJ, Osborne JL, Perry JN, Roy DB, Woiwod IP, Firbank LG. 2003. On the rationale and interpretation of the farm-scale evaluations of genetically-modified herbicide-tolerant crops. Philosophical Transactions of the Royal Society of London B 358 (1439), 1779-1800.

Squire GR, Rodger S, Wright G. 2000. Community-scale seedbank responses to less intense rotation and reduced herbicide input. *Annals of Applied Biology* 136, 47-57.

[8] Seedbank, as one word, is used throughout to indicate the populations of seed in soil; 'seed bank' usually means a collection of seed, for example in a herbarium or botanic garden.
[9] Scottish Government Strategic Research Programme 2011-2016 http://www.scotland.gov.uk/Topics/Research/About/EBAR/StrategicResearch/future-research-strategy/Themes
[10] Centre for Sustainable Cropping, Balruddery, near Dundee. http://www.hutton.ac.uk/about/facilities/centre-sustainable-cropping
[11] Scottish Government funding 2006-11: this work was carried out in the *Sustainable Crop Systems* workpackage

Weeds as biodiversity – their role in food webs

Only a few weed species are detrimental to crops: in the UK they are four or five grass weeds and one or two dicot (broadleaf) weeds. Most of the few hundred other weed species in arable farmland are largely neutral or beneficial. Here, weeds and the invertebrates they support are defined by functional types based on life history traits. A large part of this topic aims to quantify arable food web to show links between functional types such as detritus feeders, herbivores, omnivores, predators and parasitoids[12]. Factors that encourage beneficials, such as insect predators and pollinators, are deployed in IPM schemes.

Contact: Cathy Hawes (cathy.hawes@hutton.ac.uk), Geoff Squire and Alison Karley. Current funding: SG SRP Ecosystem Services Theme and Land Use Theme. Previous funding: SG 2006-11; Defra.

Storkey, J., Brooks, D., Haughton, A., Hawes, C., Smith, B., Holland, J. 2013. Using functional traits to quantify the value of plant communities to invertebrate ecosystem service providers in arable landscapes. Journal of Ecology 101 (1) 38-46.

Hawes, C., Haughton, A.J., Bohan, D.A., Squire, G.R. 2009. Functional approaches for assessing plant and invertebrate abundance patterns in arable systems. Basic and Applied Ecology, 10, 34-47.

Parish, D.M.B., Hawes, C., Iannetta, P.P.M. & Squire, G.R. 2009. The contribution of arable weeds to biodiversity. In: Kingely, R. (ed.). *Weeds: Management, Economic Impacts and Biology.* Nova Publishing, New York, USA, Chapter 4, 61-76.

Marshall, E.J.P., Brown, V.K., Boatman, N.D., Lutman P.J., Squire, G.R. & Ward, L.K. 2003. The role of weeds in supporting biological diversity within crop fields. Weed Research 43, 77-89.

Marshall J, Brown V, Boatman N, Lutman P, Squire G. 2001. The impact of herbicides on weed abundance and biodiversity. Final Report of Project PN0940, Defra, London.

A model weed – shepherd's purse *Capsella bursa-pastoris*

The common weed species owe their resilience and persistence to variation in life-history traits within the species. The genus *Capsella* provides a suitable 'model' on which to base a range of studies in such intra-specific variation. *Capsella bursa-pastoris* is currently the commonest broadleaf (dicot) weed of fields. It generally causes little competitive reduction of the crop, provides food and shelter to beneficial invertebrates and has close synteny with the plant genetic model *Arabidopsis*. Variants are characterised by both physiological and molecular techniques. Studies range from broad scale analysis of the functional types that inhibit farmland, the effects of field management on functional types and the variation in important processes such as seed mucilage expansion and seed dormancy. The potential of Capsella as a medicinal and food plant is also being explored.

Contact: Pietro Iannetta (pete.iannetta@hutton.ac.uk) . Current funding: SG SRP 2011-16; PhD studentships. Previous funding: SG *Sustainable crop Systems* 2006-11.

Toorop, P.E., Cuerva R.C., Begg, G.S., Locardi, B., Squire, G.R. & Iannetta, P.P.M. 2012. Co-adaptation of seed dormancy and flowering time in the arable weed *Capsella bursa-pastoris* (shepherd's purse). *Annals of Botany* **109**, 481-489.

Iannetta, P.P.M. 2010. *Capsella*. In, *Wild Crop Relatives: Genomic and Breeding Resources - Oilseeds*. Kole C. (Ed.). Pp 37-62, Springer, Heidelberg, Dortrecht, London and New York. ISBN 978-3-642-14870-5

Debeljak, M., Squire, G.R., Demšar, D., Young, M.W., Džeroski, S. 2008. Relations between the oilseed rape volunteer seedbank, and soil factors, weed functional groups and geographical location in the UK. *Ecological Modelling* 212, 138-146.

[12] Mostly small wasps that lay eggs in pests such as aphids: the eggs hatch into larvae that eat the aphid.

Broadley, M.R., White, P.J., Hammond, J.P., Graham, N.S., Bowen, H.C., Emmerson, Z.F., Fray, R.G., Iannetta, P.P.M., McNicol, J.W., May, S.T.(2008) Evidence of neutral transcriptome evolution in plants. *New Phytologist* **180,** 587-593. See also: Chin, G., Yeston, J. Eds. (2008) Evolution: Neutral Plantings. In, *Editors Choice*. *Science* **322,** (5898; Oct).

Karley, A.J., Hawes, C., Iannetta, P.P.M., Squire, G.R. 2008. Intraspecific variation in *Capsella bursa-pastoris* in plant quality traits for insect herbivores. *Weed Research* **48**, 147-156.

Iannetta, P.P.M., Begg, G.S., Hawes, C., Young, M.W., Russell, J.R. & Squire, G.R. 2007. Variation in *Capsella* (shepherd's purse): an example of intraspecific functional diversity. *Physiologia Plantarum* **129**, 542-554.

See also Deng et al. (2011, 2012); Begg et al. 2012.

Complex dynamics and evolution of weed populations

Weeds undergo complex life-cycle dynamics involving the buried seedbank, emerged populations, reproduction, dispersal, geneflow and genetic change. Individual-based models (IBMs) of plant populations have been an integral part of the programme since the late 1990s, finding specific use by predicting coexistence of GM and non-GM traits and trait shifts due to environment and management. The IBMs developed here have their base in flux-based studies of crop production: each individual explores the environment for a finite resource on which it grows, reproduces and disperses. The emergent properties of the resulting populations are measured in terms of mass, resource, abundance, etc. A range of other approaches are used, including machine-learning techniques for mining large datasets.

Contacts: Graham Begg (graham.begg@hutton.ac.uk) for landscape models and current IBM, Cathy Hawes for trophic interactions, Geoff Squire for weed dynamics and GM coexistence. Current funding: SRP Land Use Theme, EU FP7 PURE project[13]. Previous funding includes: BBSRC Geneflow in Agriculture, University of Abertay; BBSRC LINK on farmland diversity; PhD studentships; EU FP6 SIGMEA[14] project.

Bagavathiannan M.V., Begg G.S., Gulden R.H., Van Acker R.C. 2012. Modelling the dynamics of feral alfalfa populations: implications for novel trait confinement. PLoS ONE 7(6):e39440.

Bohan, D.A., Powers, S.J., Champion, G., Haughton, A.J., Hawes, C., Squire, G.R., Cussans, J., Mertens, S.K. 2011. Modelling rotations: can crop sequences explain arable weed seedbank abundance? *Weed Research* **51**, 422-432.

Begg G.S., Hockaday S., McNicol J.W., Askew M., Squire G.R. 2006. Modelling the persistence of volunteer oilseed rape (*Brassica napus*). Ecological Modelling 198: 195-207.

Bown, J.L., Pachepsky, E., Eberst, A., Bausenwein, U., Millard, P., Squire, G.R. & Crawford, J.W. 2007. Consequences of intraspecific variation for the structure and function of ecological communities Part 1: Model development and predicted patterns of diversity. *Ecological Modelling* **207**, 264-276.

Pachepsky E., Crawford J.W., Bown J.L., Squire G.R. 2001. Towards a general theory of biodiversity. *Nature* 410, 923-926

The role of weeds, volunteers and ferals in geneflow and persistence

Crops give rise to volunteers (weeds within fields) and ferals (living outside fields) that can hold and transmit genes and traits and interact with wild plant relatives. Volunteers such as oilseed rape and beet are important competitors of crops. Volunteers and ferals cause significant problems for managing coexistence between different types of crop, particularly GM and non-GM varieties. Research in this area

[13] PURE is the short name for the EU FP7 project Innovative Crop Protection for Sustainable Agriculture http://www.pure-ipm.eu/project

[14] SIGMEA is the short name for Sustainable Introduction of GMOs into European Agriculture, funded under EU FP6. http://www6.inra.fr/sigmea

began in the early 1990s and by a combination of population biology, landscape-scale approaches, molecular detection and modelling assumed a global lead. Concepts, methods and models are increasingly relevant to a range of non-GM problems.

Contact: Geoff Squire (geoff.squire@hutton.ac.uk) for geneflow and coexistence or Graham Begg for statistics and modelling. Current funding: EU FP7 AMIGA[15]; PhD project. Previous funding: many projects from Defra UK, Scottish Government, BBSRC, NERC, EU FP6 SIGMEA.

Devos, Y., Hails, R.S., Messéan, A., Perry, J.N. & Squire, G.R. 2012. Feral genetically modified herbicide tolerant oilseed rape from seed import spills: are concerns scientifically justified? *Transgenic Research* **21**, 1-21

Sausse, C., Colbach, N., Squire, G.R. & Young, M.W. 2012. How to manage the impact of gene flow on oilseed rape grain quality? Simulation case studies of three contrasted landscapes. *European Journal of Agronomy* **38**, 32-42

Bagavathiannan M.V., Gulden R.H., Begg G.S., Van Acker R.C. 2010. The demography of feral alfalfa *(Medicago sativa* L.) populations occurring in road side habitats in southern Manitoba, Canada. Environmental Science and Pollution Research 17: 1448-1459.

Squire, G.R., Breckling, B., Pfeilstetter, A.D., Jorgensen, R.B., Lecomte, J., Pivard, S., Reuter, H. & Young, M.W. 2011. Status of feral oilseed rape in Europe: its minor role as a GM impurity and its potential as a reservoir of transgene persistence. *Environmental Science and Pollution Research* **18**, 111-115.

Messéan, A., Squire, G.R., Perry, J.N., Angevin, F., Gomez, M., Townend, P., Sausse, C., Breckling, B., Langrell, S., Dzeroski, S. & Sweet, J. **2009**. Sustainable introduction of GM crops into European agriculture: a summary report of the FP6 SIGMEA research project. *Oléagineux, Corps Gras, Lipides* **16**, 37-51.

Begg, G.S., Elliott, M.J., Cullen, D.W., Iannetta, P.P.M. & Squire, G.R. 2008. Heterogeneity in the distribution of genetically modified and conventional oilseed rape within fields and seed lots. *Transgenic Research* 17, 805-816.

Begg, G.S., Cullen, D.W., Iannetta, P.P.M. & Squire, G.R. 2007. Sources of uncertainty in the quantification of genetically modified oilseed rape contamination in seed lots. *Transgenic Research* **16**, 51-63.

Timmons AM, Charters Y, Crawford JW, Burn D, Scott S, Dubbels SJ, Wilson NJ, Robertson A, O'Brien ET, Squire GR, Wilkinson MJ. 1996. Risks from transgenic crops. *Nature* 380, 487.

See also Bagavathiannan et al. 2012.

Impacts of GM herbicide tolerant cropping on farmland biodiversity

The UK's Farm Scale Evaluations of genetically modified herbicide tolerant (GMHT) crops is the largest field experiment on the ecology of agricultural land[16]. The main phase of experimentation between 2000 and 2004 compared effects on biodiversity of GMHT and conventional varieties of beet, maize, spring oilseed rape and winter oilseed rape occurred. The study brought to attention the strong links between field management and the functioning of food webs in farmland which have beneficial properties in pest control and pollination. The unique data generated continue to be analysed and used as a baseline in current work.

Contacts: Geoff Squire or Cathy Hawes. Current funding: EU FP7 AMIGA. Previous funding: many projects by e.g. Defra, NERC, EU, Scottish Government.

Debeljak, M., Squire, G.R., Kocev, D., Hawes, C., Young, M.W., Džeroski, S. 2011. Analysis of time series data on agroecosystem vegetation using predictive clustering trees. *Ecological Modelling* 222, 2524-2529.

[15] AMIGA is the short name for *Assessing and Monitoring the Impacts of Genetically modified plants on Agro-ecosystems* funded under EU FP7. http://www.amigaproject.eu/

[16] The main part of the study on spring-sown beet, maize and oilseed rape crops was published in *Philosophical Transactions of the Royal Society B*, volume 358, 2003.

Squire, G.R., Hawes, C., Begg, G.S. & Young, M.W. 2009. Cumulative impact of GM herbicide-tolerant cropping on arable plants assessed through species-based and functional taxonomies. *Environmental Science and Pollution Research* **16**, 85-94.

Bohan, D.A., Boffey, C.W.H., Brooks, D.R., Clark, S.J., Dewar, A.M., Firbank, L.G., Haughton A.J., Hawes, C., Heard, M.S., May, M.J., Osborne, J.L., Perry, J.N., Rothery, P., Roy, D.B., Scott, R.J., Squire, G.R., Woiwod, I.P., Champion, G.T. 2005. Effects on weed and invertebrate abundance and diversity of herbicide management in genetically modified herbicide-tolerant winter-sown oilseed rape. *Proceedings of the Royal Society B*. 272, 463-474

Perry, J.N., Firbank, L.G., Champion, G.T., Clark, S.J., Heard, M.S., May, M.J., Hawes, C., Squire, G.R., Rotherey, P., Woiwod, I.P., Pidgeon, J.D. 2004. Ban on triazine herbicides likely to reduce but not negate relative benefits of GMHT maize cropping. *Nature* 428, 313-316.

Hawes, C., Haughton, A.J., Osborne, J.L., Roy, D.B., Clark, S.J., Perry, J.N., Rothery, P., Bohan, D.A., Brooks, D.R., Champion, G.T., Dewar, A.M., Heard, M.S., Woiwod, I.P., Daniels, R.E., Young, M.W., Parish, A.M., Scott, R.J., Firbank, L.G., Squire, G.R. 2003. Responses of plant and invertebrate trophic groups to contrasting herbicide regimes in the Farm Scale Evaluations of genetically-modified herbicide-tolerant crops. *Philosophical Transactions of the Royal Society of London B*. 358 (1439) 1899-1913

Heard MS, Hawes C, Champion GT, Clark SJ, Firbank LG, Haughton AJ, Parish AM, Perry JN, Rothery P, Scott RJ, Skellern MP, Squire GR, Hill MO. 2003 Non-crop plants in fields with contrasting conventional and genetically modified herbicide-tolerant crops. 1 Main effects of treatments. Philosophical Transactions of the Royal Society of London B 358 (1439), 1819-1832.

Firbank LG, Dewar AM, Hill MO, May MJ, Perry JN, Rothery P, Squire G, Woiwod IP. 1999. Farm scale evaluation of GM crops explained. *Nature* S*cientific correspondence*, 339, 727-728

The Living Field and ASIS – examples of outreach

The Living Field project highlights the diversity and roles of the weed flora in the Living Field community garden and has general articles on weeds, volunteers and ferals and legumes as wild plants, weeds and crops (links below). The Arable Seed Identification System (ASIS) constructed by staff at the Institute and IT students at the University of Abertay Dundee is a web based guide to weed seeds and seedlings.

Contacts: Gladys Wright (gladys.wright@hutton.ac.uk) for Living Field Garden and ASIS, Geoff Squire for *5000 years* and web site. Funding: various charitable grants, for details see http://livingfield.hutton.ac.uk/news/about.

Weeds http://livingfield.hutton.ac.uk/science/5000years/plants/weeds

Crops than become weeds http://livingfield.hutton.ac.uk/science/5000years/plants/weedcrops

Legumes - weeds and wild plants http://livingfield.hutton.ac.uk/science/5000years/plants/legumes

ASIS Seed Identification Guide http://asis.scri.ac.uk/

New topics

Seed biology and soil engineering

The mucilage emitted by seeds on being wetted helps to bind them to the soil, attracts water, protects them against bacteria and fungi and may be beneficial to local soil stability. Moreover, the mucilage has properties that might guide the design of engineering solutions for stabilising and revegetating slopes. Such bio-mimicry is becoming an important topic in our developing portfolio in weed ecology.

Contact: Pietro Iannetta (pete.iannetta@hutton.ac.uk). Initial funding: joint CECHR[17] research studentship between JHI and the University of Dundee (ended 2013).

Deng W, Iannetta PPM, Hallett PD, Toorop PE, Squire GR, Jeng D-S 2013. The rheological properties of the seed coat mucilage of *Capsella bursa-pastoris* L. Medik. (shepherd's purse) (2013) *Biorheology* 50, 57-67 DOI 10.3233/BIR-130627

Deng, W., Jeng, D.S., Toorop, P.E., Squire, G.R. & Iannetta, P.P.M. 2012. A mathematical model of mucilage expansion in myxospermous seeds of *Capsella bursa-pastoris* (shepherd's purse). *Annals of Botany* 109, 419-427.

Currencies for evaluating the positive and negative effects of weeds

The search for a currency through which to place a value on the positive and negative effects of weeds in now concentrating on nitrogen, which is a major constituent of plants and also a fertiliser, which, while essential for yield, is one of the most serious pollutants released by agriculture. Weed populations that support an active food web are being valued in terms of the cost of nitrogen fertiliser.

Contact: Alison Karley (alison.karley@hutton.ac.uk). Current funding: SG SRP Theme 1.

Landscape-scale influences

The concept that landscape as well as in-field management can affect the presence and abundance of weeds is an engaging new approach. Here, landscape consists of the fields and other parcels of land arranged in space and time, e.g. incorporating sequences of crops and field management. Exploratory work is being carried out in the Maritime Study Region based in the east of Scotland.

Potential: informing policy on arable land use and biodiversity; landscape scale cooperation in optimising production and biodiversity.

Contact: Graham Begg (graham.begg@hutton.ac.uk) Initial funding: SRP Land Use Theme, 2011-16; PURE project on integrated pest management.

Environmental impact/risk assessment/restoration

Knowledge of seeds, plants, invertebrates and food webs is increasingly in demand as a background to ecological or environmental risk assessment. For example, engineering projects that impinge on farmland, such as the laying of long-distance pipelines, need to be assessed for their impact on the arable flora and food web. And expertise in GM crops and pesticides is combined to facilitate a broad, system-scale approach to the risk assessment of biotech crops.

Contact: Geoff Squire (geoff.squire@hutton.ac.uk) and Nick Birch (nick.birch@hutton.ac.uk). Current funding: EU FP7 AMIGA; National Grid.

Birch, A.N.E., Begg, G.S., Squire, G.R. 2011. How agro-ecological research helps to address food security issues under new IPM and pesticide reduction policies for global crop production systems (Invited Review). *Journal of Experimental Botany* **62**, 3251-3261.

EFSA 2010 Guidance on the environmental risk assessment of genetically modified plants. EFSA Journal 2010, 8(11):1879 [111 pp.] doi:10.2903/j.efsa.2010.1879[18]

[17] Centre for Environmental Change and Human Resilience, Dundee http://www.dundee.ac.uk/centres/cechr/
[18] EFSA: European Food Safety Authority http://www.efsa.europa.eu/ (contribution to authorship by G R Squire)