PERSPECTIVE

Prospects for Applied Weed Research – a Perspective

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Editor's Note:
This perspective from Stephen Moss is re-published for the benefit of weed scientists in the Asian-Pacific region. Originally, the Author posted his perspectives on the *European Weed Research Society* (EWRS) Website on 6th April, 2023 (see: **https://www.ewrs.org/en/info/Blog//109**). Although written primarily from a western European agronomic perspective, the ideas about applied weed research activities that Stephen Moss presents are scientifically sound, and, more importantly, practically relevant to all weed scientists globally.

Introduction

As I will soon retire from active research, after over 50 years, I thought a list of applied topics requiring more research might have merit. I am certainly not suggesting that all of these are original, novel or have never been studied previously. But, in my opinion, there is scope for undertaking more research that is both good scientifically and, more importantly, has real practical application.

If I have one criticism of current weed research it is that too much emphasis is placed on knowledge acquisition rather than its practical application. And surely, weed research is an applied discipline?

In the UK, there has been a catastrophic decline in the number of research centres conducting applied, independent, agricultural research during the last 40 years. These are documented in an article in the *UK Crop Production Magazine* (CPM) to celebrate my 'golden' research anniversary [1]

State funding tends to be focussed on basic studies, and research centres are increasingly dependent on commercial organisations for funding more applied projects. So, what is the difference between 'basic' and 'applied' research? Put simply, 'basic research' can be considered an 'end in itself' and judged purely on its scientific merit ('high impact' research papers). In contrast, 'applied research' can be considered 'a means to an end' and is better judged by its impact in the 'real' agricultural world. Ideally, a continuum would exist right across the research spectrum but, in the UK, funding tends to be polarised at one end or the other, with the 'valley of death' of translational research in between. My greatest achievement is surviving in the 'valley of death' for over 50 years.

The topics I wish to highlight below are presented with a limited amount of explanation. They are predominantly from a UK and a grass-weed perspective but have wider relevance too. Topics are listed under four broad categories: Weed Biology; Herbicides; Weed Evolution; Student-type projects.

[1] See pages 8–12 in the October 2022 issue: **https://www.cpm-magazine.co.uk/back-issues/crop-production-october-2022/**).

Stephen Moss's presentation is also available for viewing on U-Tube (**https://www.youtube.com/watch?v=gDmpdhLs8As**).

Weed Biology

**Topics currently being studied in a Syngenta-funded PhD at NIAB/University of Lincoln.*

1. Reducing weed seed return. Harvest Weed Seed Control (HWSC) is receiving a great deal of attention, but other aspects are important too.

a. In-crop patch spraying with glyphosate is widespread but what are the practicalities and benefits of spraying the same patches for several years? Factors to consider include spraying strategies, environmental benefits, impact on resistance and cost savings.

Drones could be used to detect and spray small weed patches annually. How much do the benefits vary with weed species?

b. Hand roguing (hand-pulling) – effectiveness and feasibility with different species. What is realistic?

c.* Grass-weed head ‘surfing’ - cutting weed heads just above crop pre-harvest. Factors to consider: crop/weed height differential; timing and benefit of multiple cuts; effect on seed viability and dormancy; regrowth; crop yield response.

Do crop growth regulators or drilling date affect the crop/weed height differential and can this be used to improve control?

d. ‘Hoovering’ up recently shed weed seeds from the soil surface immediately behind the combine header before straw is deposited on top (ideally combined with HWSC for seed destruction).

2. Post-harvest stubble management to maximise weed seed loss. Research has shown that incorporating freshly shed seeds of most weed species into the soil helps preserve them, whereas leaving them on the soil surface encourages loss. Despite this, many UK farmers cultivate straight after harvest to incorporate straw residues and encourage germination of crop volunteers.

a.* Is delaying cultivations by several weeks prior to sowing spring crops a realistic option, what delay is acceptable and are there soil/environmental benefits? How do cover crops affect this?

b.* Can we better quantify any benefits, and how they are influenced by the numerous variables which include: weed species, the relative number of freshly shed vs older seeds in the seedbank, duration of delay, type and amount of crop residues, type of cultivation, the weather, seed dormancy, and sowing date? This requires investigation in real field conditions, at multiple-sites, over multiple-years, to reach robust, practical conclusions.

3. Maximizing the value of grass leys/non-crop cover crop breaks/fallowing within arable rotations. Any ‘break’ in an arable cropping sequence has the potential to totally prevent any grass-weed seed return. This should result in a substantial reduction in the weed seedbank of annual grass-weeds, such as slender foxtail (*Alopecurus myosuroides*) and ryegrass (*Lolium* spp.), which typically have annual seedbank declines of about 70%. But lack of cultivation means that seed decline is likely to be less than under annual tillage regimes.

a. There is a lack of information on the best policy to adopt at the end of a non-crop ‘break’: is it ‘maximum’ cultivation (to encourage germination of residual seeds) or ‘minimum’ cultivation (to leave buried residual seeds undisturbed)?

b. In theory, maximum cultivation during conditions favourable for weed seed germination, followed by a stale seedbed lasting several weeks and glyphosate spray prior to sowing the next crop should be the best approach to exhaust the weed seedbank.

Practical evidence to support this is needed and also to determine what delay to sowing the next crop is desirable (weeks or months?) to maximise the benefit. Failing to adopt the best approach could potentially undermine the benefit achieved over several years.

4. Increasing crop competition to increase weed suppression in the field. Hardly a novel concept but are glasshouse/CE weed/crop competition studies ever relevant to field situations? A pertinent question. Certainly, there is scope for more applied, field-based studies. For example:

a. The principle that some varieties of a wide range of different arable crops are more competitive against weeds than others has been demonstrated numerous times. Applying this in practice has been less successful, partly because the commercial life-span of any individual variety tends to be short.

What is required is the development of a simple, field-based, protocols that can be used routinely to assess the competitive ability of new varieties, ideally before release. One approach might be to use a split plot design with, for each variety, crop only (e.g. wheat) compared with crop + model sown weed (e.g. wheat plus rye-grass).

The number of rye-grass heads would be a direct measure of variety competitiveness and relative crop yield would be a good metric of direct relevance to farmers. Crop traits, which confer competitiveness advantages, could be investigated in the field.

Even if unsuccessful, such research would not detract from the more practically useful information that can be obtained.

b. In the UK, oilseed rape crops direct drilled into cereal stubble will usually receive some fertilizer at sowing. If this is applied to the soil surface, weeds such as *Alopecurus myosuroides* benefit as much as the crop, but if this is placed below the crop seed, the emerging oilseed rape plants may gain a competitive advantage over the weeds due to greater access to nutrients. Additional benefits may be that the less vigorous weeds are more easily controlled with post-emergence herbicides (e.g. propyzamide) and the crop more able to withstand pest attack (e.g. cabbage stem flea beetle).

More broadly, this topic seeks to answer the question: can the relative competitive ability of crops and weeds be assessed under contrasting agronomic situations and the practical benefits quantified in a practically useful way?

Herbicides

1. Pre-emergence herbicides issues. With *Alopecurus myosuroides* and *Lolium* spp., ever-increasing resistance to post-emergence herbicide has resulted in ever-increasing reliance on pre-emergence herbicides. Three related issues deserve field investigations:

a. The negative impact of increasing soil organic matter on the efficacy of pre-emergence herbicides. Reduced tillage, or the addition of organic manures, can result in rapid increases in surface organic matter. Although this situation is beneficial from a soil health perspective, one downside is the likely reductions in efficacy of residual herbicides due to adsorption. Any reductions in efficacy are likely to be gradual and vary with individual herbicides.

b. Resistance. Despite resistance to the pre-emergence herbicides used for grass-weed control in the UK being widespread, resistance tends to be partial and increase slowly. Hence, pre-emergence herbicides have had greater longevity than many post-emergence herbicides.

c. Enhanced microbial degradation in soil. Previous research has demonstrated enhanced degradation of many of the pre-emergence herbicides currently used in Europe (e.g. pendimethalin, prosulfocarb, tri-allate). However, the impact of this on efficacy in the field has rarely been characterised.

Each of these three factors is likely to reduce the efficacy of pre-emergence herbicides in a slow, progressive manner – changes that are likely to be undetectable in the field in the short-term. However, the combined impact could be at least additive, especially if future regulatory restrictions require rates of use to be reduced.

With increased reliance on pre-emergence herbicides in cereals, the impact and interaction of the above three factors on long-term herbicide efficacy deserves attention. Do different active ingredients respond to each of the three factors differently?

Almost certainly, the answer is yes, but I am not aware of any independent research done on this in a systematic way. Modelling the effects of the three factors alone, and combined, might help in predicting long-term impacts. This would make a great Ph.D. project for a future student.

2. Why does the efficacy of pre-emergence herbicides vary between farms? In the UK, flufenacet + pendimethalin and flufenacet + diflufenican have been widely used for pre-emergence control of grass-weeds for over 20 years.

On average, both give the same control of *A. myosuroides* (mean 71% across 375 field trials, Hull *et al,* 2014). But on individual fields, one mixture can be consistently superior to the other. Why? We don't know - and there is anecdotal evidence that the efficacy of other herbicides (e.g. prosulfocarb) also varies consistently between fields.

a. At least 12 factors influence the efficacy of pre-emergence herbicides: soil moisture; rainfall intensity; seedbed quality; soil organic matter; surface crop residues; weed seed distribution in soil; weed germination pattern; application technique; temperature; enhanced microbial degradation, cultivations and resistance. Determining the relative influence of each of these individually, and combined, is a considerable challenge. However, investigating their relative impact on individual herbicides - and how they might be modified – would be useful. Surely, it is farmer's long-term interests to know what herbicides work best – and the underlying reasons for this – on their own individual farm?

3. Benefit of adjuvants, water conditioners, new nozzles and other herbicide 'performance enhancers'. These all have valid uses but most claims in the UK farming press for the benefits of specific products are not supported by any truly independent evaluation.

Farmers and agronomists would benefit greatly from simple multi-site and multi-year trials conducted fully independently. Studies at half the recommended herbicide rates might more readily demonstrate their potential benefits, even if overall control was inadequate. This experimental approach should be used more widely.

4. Herbicide Resistance. There is an ongoing need to detect and investigate new types of resistance, especially those conferring partial resistance where interpretation can be problematic.

Resistance may evolve faster under the reduced tillage systems which are now being actively promoted. Diagnostic assays that are readily accessible to farmers and agronomists are needed, as is availability of well characterised reference populations. Detection and interpretation of resistance should not be left solely to the agrochemical industry.

Weed Evolution

These topics are more ‘academic’, but also have some practical relevance. Weeds are often under intense selection pressure and many species can evolve rapidly with time. Herbicide resistance, now prevalent in many species, is a good example. Relevant studies include:

1. Have individual weed species become genetically more competitive over time? If herbicides can select for more resistant individuals, would one not expect intense competition from crops also to select for genetically more competitive individuals? Changes in agronomy (e.g. sowing date) may affect crop/weed competitive balance too, which would affect phenotypic expression of competitiveness, so this is a challenging academic study.

Are ‘superweeds’ evolving? (Since drafting this section, I was pleased to note the publication of the first study providing direct evidence of evolution of competitive ability in a plant species (*Setaria faberi*); Ethridge *et al.*, 2023, Weed Science 71: 59-68.)

2. Have weed germination and emergence patterns changed? Claims about changing patterns of grass-weed emergence are not well supported by good independent data. The influence of changing cropping and cultivation practices (and possible indirect effects of resistance) on emergence patterns of *Alopecurus myosuroides*, *Lolium* spp. and *Bromus* spp. would be a useful study and relevant to IWM. Quantifying and explaining inter-population variation would be very useful too.

3. Do resistant weed seeds survive longer in the soil than susceptible ones? If so, then this is likely to be weed species and resistance mechanism specific.

If proven, it would indicate (for the first time?) selection pressure for herbicide resistance operating in the absence of herbicides - the proportion (but not number) of resistant individuals increasing with time.

4. Do resistant weed seeds have greater dormancy than susceptible ones? If so, then this is likely to be weed species and resistance mechanism specific. In UK, the *Alopecurus myosuroides* population with the greatest ability to metabolise herbicides (Peldon population) has shown the highest degree of innate dormancy in each of the past 20 years, based on annual seed collections totalling over 700 populations. This seems an unlikely coincidence.

However, the fields at Peldon have, for over 50 years, been in continuous winter wheat which has always been sown relatively late in autumn. Selection for high innate dormancy could be a consequence of late sowing, or pleiotropically linked to enhanced metabolic resistance, or both factors, or neither. A degree of enhanced metabolic resistance occurs in most *A. myosuroides* populations in the UK, so it is possible (but unlikely) that changes in emergence patterns are directly linked with resistance. Determining the factor(s) responsible would be relevant to IWM and resistance management.

5. How important is ‘pre-selection’ for resistance to herbicides? It has been hard to explain the speed – often less than 10 generations – at which weeds evolve resistance to a level which impacts on control in the field. One factor that has often been overlooked is the low level of selection (= ‘pre-selection’) conferred by herbicides that make no claims for control of a specific weed.

For example, in the UK, metsulfuron has been widely used for broad-leaved weed control for over 35 years. While there are no label claims for control of grass-weeds, it does have activity on weeds, such as *Alopecurus myosuroides* and *Lolium* spp. The relatively low level of selection conferred in such situations might well be important in relation to the speed of subsequent selection conferred by herbicides with greater grass-weed activity (e.g. mesosulfuron). Studies on such ‘low level pre-selection’ might help explain the dynamics of resistance evolution and help quantify longer-term resistance risks.

6. How quickly can ‘weediness’ traits evolve? At least some ‘weedy’ traits (e.g. extended germination patterns, longer seed persistence, greater competitiveness and resistance) have evolved in the cultivated grass species *Lolium multiflorum* in the UK.

This was introduced into the UK in 1831 for grazing and hay making and plant breeding has subsequently produced a wide range of cultivars with different characteristics. It is now found increasingly as a weed of arable crops and resistance is widespread. This makes it an ideal candidate for a UK study on how a 'crop' becomes a 'weed' – especially as other weedy *Lolium* species (e.g. *Lolium rigidum*) are rare. (*Lolium perenne* is very common but rarely occurs as a major arable weed in the UK).

Important questions include: how much do weediness traits vary between field populations; how might these traits evolve further in future; are resistant populations in the UK derived from identifiable cultivars? has resistance evolved independently in specific cultivars or has it been introduced via pollen from existing resistant populations?

Are some cultivars more resistance-prone than others and, if so, why? Do modern breeding techniques make 'weediness' more, or less, likely to evolve? There may be other, more appropriate candidate species, in other countries. Characterising the dynamics, mechanisms and implications of how such a crop evolves into a weed would make a great academic study.

7. Why don't *A. myosuroides* and *Lolium multiflorum* co-exist as weeds of arable crops? These are both major weeds of UK arable crops and, while mixed populations do occur, one species usually dominates. Infestations comprising similar densities of the two species are rare — although they may occur in different patches within the same field. Why?

The obvious reasons, such as cropping and herbicide history, soil type and drainage do not appear to offer a full explanation. *Lolium multiflorum* is twice as competitive as *A. myosuroides* on an individual plant basis and this may be a contributing factor. Is the reason these two species 'do not like each other' some allelopathic effect? Could it be linked to subtle differences in resistance to herbicides, which is common in both species in the UK? Research on this topic would be relevant to a better understanding of the dynamics of patches of such weeds.

Student-type projects

The following are smaller scale student-type projects , which can be on specific issues.

1. Is fresh, or dry foliage weight a better metric for determining herbicidal effects on plants in glasshouse pot tests? Foliage weights are often used to quantify the degree of herbicidal activity on weeds, as a representation of 'aliveness' and 'deadness'.

Recording dry weights, after the removal of the major constituent of living plant material, namely water, seems illogical. Despite this, reviewers of papers submitted to journals often favour use of dry weights. But foliage fresh weights, recorded immediately after cutting, may not only be a better metric scientifically, but also save time, energy and money. A critical study on this would be useful. (Of course, dry weights are a better metric in many other scenarios, especially where plants wilt before weighing).

2. Why does % emergence of cereals (and other crops?) tend to decline with increasing seed rate? In the UK, higher cereal seed rates are one of the most widely used ways of increasing crop competitiveness against grass-weeds.

It has been noted in field trials that % establishment decreases with increasing seed rate, although the reasons for this are rarely explained. Clearly, this effect will result in diminishing marginal benefits as seed rate increases, so investigating this could be useful in avoiding wasting crop seeds as a consequence of increasing seed rate excessively.

3. Can the assessment of herbicide resistance in Petri-dish assays be speeded up? Petri-dish seedling growth assays for determining herbicide resistance often require a time-consuming assessment of shoot length for each germinated seed [2]. Visual assessments of % reduction in seedling growth, relative to no-herbicide controls, are quicker, but are subjective and accuracy is also dependent on the experience of the assessor.

An alternative, but more objective assessment, could involve recording the amount of 'greenness' per dish using a green canopy cover mobile phone app, such as Canopeo (**https://canopeoapp.com/**). Ideally a comparison of different assessment methods could be done, including time taken.

4. Do resistant arable grass-weeds in predominantly livestock farming areas, occur as a consequence of seed movement in contaminated straw or equipment? Resistant weeds such as *Alopecurus myosuroides*, *Lolium multiflorum* and *Avena* spp. are considered a minor issue in areas where livestock farming and grassland predominate (e.g. Wales). However, resistant weed seeds may be introduced into fields in contaminated straw (used for bedding or feed), in equipment (e.g. balers and combines) or in crop and grass seed.

Resistance tests on weed seeds collected from arable fields in such areas, especially if never treated with grass-weed herbicides, would be informative.

[2] A detailed protocol for '*The Rothamsted Rapid Resistance Test*' is available at: **https://ahdb.org.uk/knowledge-library/the-weed-resistance-action-group-wrag**.

The findings might encourage timely prevention and management strategies, such as hand roguing.

5. Do ALS-resistant seeds of *Papaver rhoeas* have less innate dormancy than susceptible seeds? ALS-resistant *P. rhoeas* occurs in 10 European countries, where it is one of the most commonly encountered resistant broad-leaved weeds.

The seeds of this species are very persistent in soils so the ‘buffering’ effect of older, less selected seeds, might have been expected to greatly moderate the rate of evolution of resistance.

But, if resistant seeds have less innate dormancy, this might explain why resistance has been recorded so widely. A study on the seed dormancy of a range of European populations, susceptible and resistant, could clarify this issue.

6. Do pre-emergence herbicides ‘sensitise’ weeds to post-emergence applications? It has often been claimed that weeds surviving pre-emergence herbicides are more easily killed by subsequent post-emergence applications.

The pre-emergence herbicides are considered to be ‘sensitising’ the survivors. This could occur if, for example, surviving plants are damaged and are therefore, more easily killed by a subsequent application. However, there is very little independent evidence to validate this claim, or to show how best to utilise it in practice. Questions to answer include: is this herbicide-specific? Can the effect be quantified; Is it a consistent trait?

7. Is a cost/benefit analysis of non-chemical weed control compared with herbicides useful? Integrated Weed Management (IWM) is promoted as a means of reducing reliance on herbicides and involves using a range of non-chemical alternatives. Individually, these alternatives may be less effective than herbicides despite costing more. However, there may well be additional benefits apart from weed control (e.g. crop rotations may have pest control and yield benefits).

There may be scope for additional studies on this topic comparing short-term (single year) and long-term (five years +) rotational benefits. The environmental and greenhouse gas impacts of non-chemical weed control, relative to herbicides, also deserve more scrutiny. This study could be useful in determining the most cost-effective and environmentally-favourable approaches and may encourage farmers to adopt the most appropriate IWM strategies on their own farms.

Final Thoughts

In relation to applied disciplines, like weed research, I fully support the view that:, *Knowledge without potential application is wasted.* The decline in funding for independent applied research in the UK is unlikely to be reversed. This situation also applies in some other countries too. Consequently, limited resources need to targeted on those projects which:

1. Require truly independent research, which companies either won’t undertake, or are unlikely to do in an objective manner.

2. Produce durable information, of relevance in the long-term.

3. Give priority to delivering robust, practical outputs rather than mere ‘academic’ studies.

4. May require multi-year and multi-site studies to convincingly answer simple questions.

5. Are not: (1) reinventing the wheel; (2) ignoring previous relevant research; (3) simply using impressive new techniques for their own sake but delivering nothing ‘new’.

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Editor’s Note: About the Author

Stephen Moss has spent over 45 years in weed research, largely on grass-weeds and especially black-grass (*Alopecurus myosuroides*). Starting in 1975, following his B.Sc. in Agriculture at Wye College in 1972, he worked at the Weed Research Organization (WRO) at Oxford, then at Long Ashton Research Station, where he gained his Ph.D. and, from 1990, at Rothamsted Research.

He has published numerous research papers, book chapters and technical reports, and contributed to a large number of articles in the popular farming press. He has given numerous talks to farmers, consultants and agrochemical company staff. Stephen was the Secretary of the UK Weed Resistance Action Group and a UK representative on the European Herbicide Resistance Working Group. He now runs a private consultancy, Stephen Moss Consulting.