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OptiSeed: **Opti**mising agronomic and biological inputs for more sustainable oil **Seed** production

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1 Abstract

This project aimed to support agricultural transition to net-zero, primarily by helping adapt oilseed rape (OSR) crop production approaches through optimisation of agronomic and biological inputs. Currently around 700 CO_2 e/tonne are produced by OSR which is greater than other arable crops. Specifically, we explored the extent to which industry-validated management adaptations might allow for the maintenance of yield under reduced inputs of fertiliser and potentially pesticide. Using online workshops and an evidence gathering exercise we identified a suite of management adaptations prioritised by growers. Promising approaches include utilising alternative nutrient sources, promoting biodiversity-based ecosystem services such as pollination and natural pest control through improving existing habitats, employing pest management thresholds, and effectively managing the crop canopy. We then developed a framework, which considers existing models and available data and highlight where DSS (Decision support systems) are required, what input data is needed and how it could be collected. We have highlighted preferred management approaches to improve production and environmental outcomes (focussing on net-zero) in oilseed crops, generated an evidence base of existing research on the effects of OSR management on yield outcomes, and identified future research opportunities. These outcomes can benefit UK OSR farmers by helping guide future research to the most appropriate DSS (decision support system) as well as shape UK policy to support farmers to continue to adapt OSR management, targeting those approaches with the greatest potential to deliver, while also being feasible within a UK farming context.

2. Introduction

To help tackle climate change, the UK has a target to reach NET ZERO by 2050 (UK Gov). The agricultural sector is a significant contributor to UK emissions (10%) (NFU) and adapting approaches to UK food production will need to be part of the solution, particularly if UK farming is to achieve NET ZERO by 2040, as proposed by the National Farmers Union (NFU). The solutions will need to be sector wide, consider all farming processes from inputs, management approaches, processing and supply chains, as well as exploiting opportunities to increase carbon stocks on farms (NFU). The challenge is relevant to all food production systems including arable, livestock and horticulture.

Oilseed rape (*Brassica napas*) is an economically important arable crop grown in rotation with cereal crops in the UK. Relative to other arable crops however, CO_2 equivalents per tonne of OSR yield are high, at ~700 CO_2 e/tonne (Townsend *et al.* 2021). In common with other arable crops, greenhouse gases (GHGs) are generated by several sources including crop processing, fertiliser application and use of farm machinery (Fig 1.)

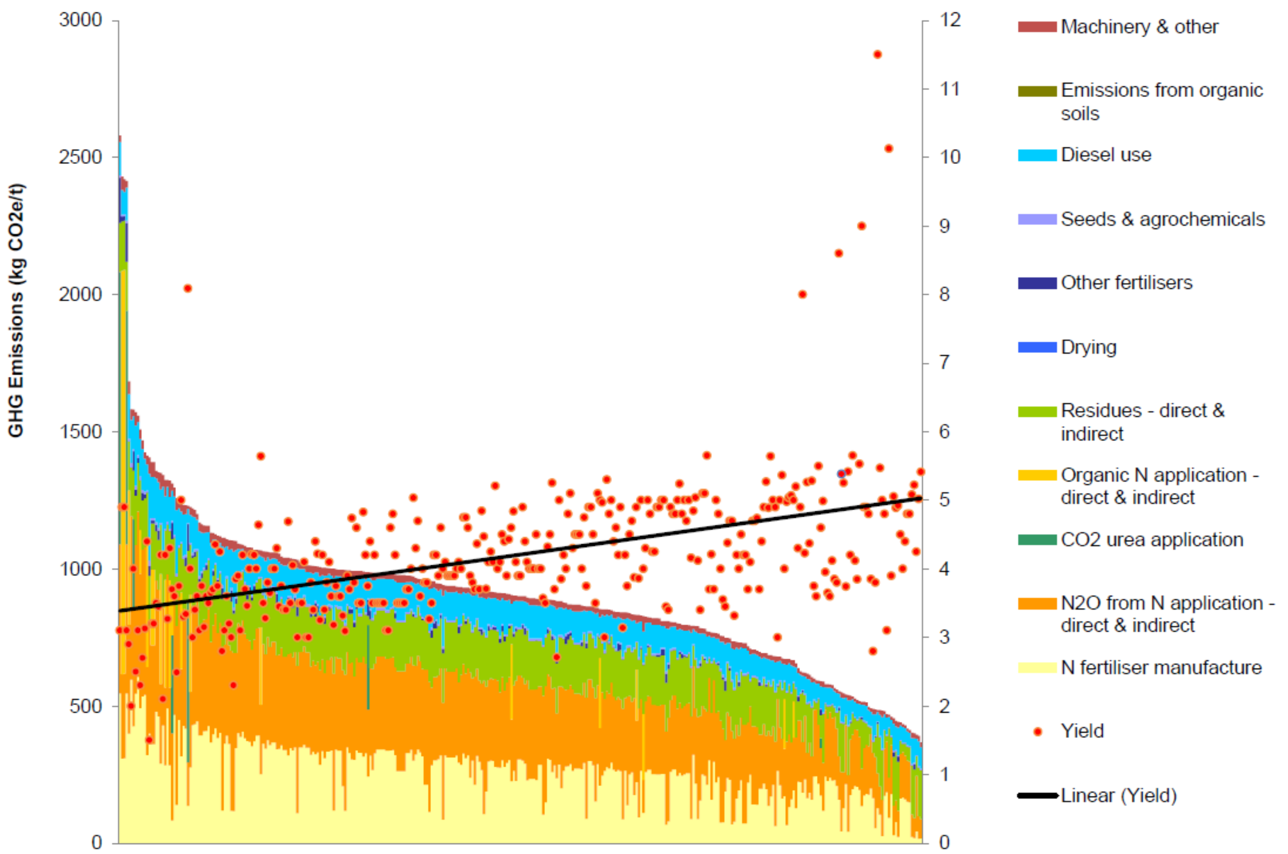

Fig 1. GHG emission intensities associated with OSR at the farm gate for 353 datasets between 2005 and 2012 with the PAS 2050 methodology (Sylvester-Bradley et al. *2015)*

What is clear is that the majority of GHG emissions in OSR production are a direct or indirect result of nutrient management, particularly application of nitrogenous fertiliser. With typical rates of 225 kg/ha and still highly variable yield (data from the Oilseed YEN 2017-2020), there is considerable opportunity to optimise inputs to deliver better (and more consistent) yield with a reduced environmental impact (e.g., reduced run-off, GHG mitigation, increased biodiversity), particularly given CO_2 e/tonne goes down consistently with increasing yield (Fig 1.). While the impact of fertiliser application on crop physiology and yield is well established (Defra, 2015; Mahli *et al*. 2007), the potential of biological inputs such as pollination by insects or pest pressure (e.g. cabbage stem flea beetle [CSFB]) to influence these parameters are less well understood.

For example, the contribution of insect pollination to OSR yield is variable and depends on variety, with yield increases of 20% observed in some cases (Hudewenz *et al.* 2013, Ouvrard *et al.* 2019). However, recent research has shown that these yield increases can interact with nitrogen availability to shape yield, and while increased seed set was consistently delivered by insect pollination, benefits to yield were only realised at higher fertiliser rates (Garratt *et al.* 2018). Cabbage Stem Flea Beetle (CSFB) is a major pest of OSR with autumn damage reducing crop density (Dewar, 2017). Given the critical role of plant density (plants per m^2) in influencing crop physiology and resulting yield (Leach *et al*. 1999, Momoh and Zhou, 2001), better control of CSFB has the potential to considerably impact the crop, how it responds to nitrogen inputs, and therefore GHG emissions. Biological and agronomic inputs do not work independently of one another and there are opportunities to co-manage these inputs for improved yield outcomes and improved NUE (nitrogen use efficiency).

Approaches that increase pollination or help control pests to promote optimal crop growth form, and therefore NUE, can also deliver additional benefits to offset GHG emissions. For example, creating or improving on-farm features like hedgerows to provide habitat for beneficial insects such as natural enemies and pollinators (Garratt, 2017) also has the potential to increase carbon captured above (Axe et al. 2018) and below ground (Biffi et al. 2022), helping to meet emissions targets. Additional benefits to biodiversity protection can also be predicted from management to create or improve non-crop habitats (Batary et al. 2015). By taking a more holistic approach to production, incorporating our knowledge of managing biological inputs such as pollinators and natural enemies of crop pests (Dainese at al. 2019, Garratt et al. 2017), and integrating this with our understanding of the role of more conventional inputs, there is an opportunity to provide improved decision support to OSR growers, indicating the impact of alternative decisions on yield, profit and GHG emissions.

The OptiSeed project aimed to support agricultural transition to net-zero by exploring opportunities to reduce intensity of cultivation and optimise agronomic and biological inputs. Specifically, this project considered oilseed rape crops and used a crop modelling and Discussion Support framework to explore the extent to which industry-validated management adaptations would allow for the maintenance of yield returns under reduced fertiliser (and potentially pesticide) inputs. We aimed to identify a suite of management adaptations and then explore their potential interactive impacts on GHG emissions and crop performance to be tested further as part of a larger scale longer-term project. OptiSeed had several primary objectives:

The first objective (**Objective 1**) was to identify a list of management options for reducing GHG emissions in oilseed rape production and to use experts and practitioners (farmers and agronomists) to identify which of these has the potential to deliver the greatest benefit in terms of yield, reduced GHG emissions but are also feasible within the current farming context. The second objective (**Objective 2)** involved exploring available research evidence on the role of biological and agronomic inputs and farm management approaches on OSR crop physiology and yield, identifying potential data gaps to help direct future research activities. The third objective (**Objective 3**) used research and data on the effects of biological (pollination, pest pressure) and agronomic (fertiliser application, sowing rates) inputs on crop physiology and potential yield, identified from Objective 2, to develop a conceptual modelling and DSS framework to determine how alternative management strategies influence yield, profitability and GHG emissions in OSR production.

3. Materials and methods

3.1 Overview

To identify the most promising opportunities to reduce GHG emissions from OSR production in the UK (Objective 1) we combined expert assessment and a stakeholder workshop to highlight management approaches which have the potential to improve crop physiology or yield and thus reduce reliance on inputs which generate high GHG, particularly conventional fertilisers. We then carried out a systematic evidence review (Objective 2) to identify relevant research and also potential evidence gaps. These approaches were employed in a step by step and iterative way to generate a list of factors to be incorporated into a final modelling framework (Objective 3) that could be utilised to explore the potential of these adaptive management approaches in future research.

3.2 Identifying management approaches

3.2.1 Expert workshop

We identified 13 ‘factors’ (e.g. reduced pest, improved pollination, optimised soil nutrients) which, if achieved through an adaptive management approach, could potentially reduce GHG emissions while achieving the same or greater yield. At a workshop of 12 researchers and academics, with a broad range of experience in sustainable crop production, including ecologists, agronomists, crop modellers and crop physiologists, we asked attendees to list factors which determine OSR yield using the ‘Wordcloud’ function in menti.com. We then checked that listed factors were covered by our 13 ‘factors’ before asking all workshop attendees to score each of these 13 factors between 1 and 5. They were asked to score each factor for two things: 1. their potential to deliver yield benefits in OSR crops, and 2. the feasibility with which they could be achieved through adaptive management. For the final activity of the workshop we outlined the approach we would take in the subsequent ‘stakeholder workshop’ and asked for feedback. Using this feedback we identified 28 adaptive management approaches falling under six categories (Table 1.) for consideration during the stakeholder workshop.

Category	Management Approach	Benefits to Yield (NUE), biodiversity & GHG emissions
Preventative pest management	1. Create new habitat: create beetle banks, establish new hedgerows or field margins to support pest predators 2. Improve existing habitat: widen field margins & hedgerows, reduce hedgerow cutting, to increase pest predators 3. Alter crop rotations: reduce weed competition, fungal pathogens & soil pest build-up 4. Create a sterile seed bed: allow weeds to germinate then spray off/till before planting crop	Prevent damage from pests and diseases Reduce competition from weeds Carbon capture Increase biodiversity
Soil management	1. Reduce tillage or use no tillage: to improve soil structure & retain soil moisture 2. Practice low traffic farming or use specialised machinery: to reduce soil compaction 3. Use precision nutrient application: regular soil assessment to target nutrient application 4. Include legumes in rotations: to restore nitrogen 5. Apply animal manure: to replace conventional N and increase soil organic matter 6. Apply green manures: to replace conventional N, improve soil structure, add organic matter, and suppress weeds 7. Use irrigation: to manage soil moisture at key growth stages 8. Use windbreaks: to reduce soil & moisture loss	Improve soil health & structure Improve crop growth Improve water & nutrient availability Carbon capture Increase biodiversity
Crop establishment	1. Select suitable sowing dates for each field: optimise germination and plant establishment by selecting sowing date based on local conditions & forecast 2. Select suitable sowing rates for each field: optimise plants per m^2 by adjusting sowing rate/ density 3. Select suitable varieties for each field: select alternative varieties adapted for local soil conditions/known pest issues	Optimise germination Optimise plant density Optimise variety
Canopy management	1. Apply micronutrients: test for and apply additional targeted micronutrients 2. Apply macronutrients: test for and apply targeted foliar macro nutrients 3. Apply plant growth regulator: test for and apply targeted plant growth regulator (PGR) 4. Optimise senescence: apply herbicide to ensure crop ripens evenly for maximum harvest	Maximise Green Area Index (GAI) Maximise yield & minimise loss
Responsive Pest management	1. Use pesticide thresholds: target timing of chemical sprays against insect pests, weeds & diseases through in-field scouting 2. Use improved application technology: use of better application technology for better targeting of pests 3. Use a resistance management strategy: use of better active ingredients (fewer/ weaker applications needed, targeted to specific pests rather than broad spectrum) 4. Make use of pest forecasting: use large scale centrally collected data on abundance and environmental conditions to predict pest pressure	Prevent damage from pests and diseases Reduce competition from weeds Increase biodiversity
Pollination	1. Create new habitat: sow wildflower margins, establish hedgerows 2. Improve existing habitat: widen field margins, reduce hedgerow cutting, increase pollen and nectar in existing field margins 3. Reduce insecticide input: use less harmful inputs, reduce number and concentration 4. Introduce honeybees: introduce honeybee hives at the field edge 5. Introduce bumblebees: provision bumblebee hives at the field edge	Improve seed set, seeds/m^2 Increase oil content Carbon capture Increase biodiversity

Table 1. List of adaptive management approaches with the potential to reduce OSR GHG emissions while improving or maintaining yield. Management approaches are grouped based on six key decision-making stages for OSR production.

3.2.2 Stakeholder workshop

To recruit farmers and agronomists to attend our workshop we sent an email invitation through our networks, including the ADAS Yield Enhancement Network (YEN) and YEN Zero network, as well as putting out a request on Twitter. We received a number of positive responses, and had eight growers and agronomists with considerable experience in OSR production available for the workshop. The workshop was run using Microsoft Teams and lasted for two hours. The participants were introduced to the project, the potential for reducing GHG emissions in UK agriculture and OSR specifically, and made aware of the specific aims of the workshop. We then carried out six scoring exercises using 'menti.com'. Each participant scored the management practices (Table 1.) within each category from 1 to 10 based on: 1. their potential to deliver yield benefits in OSR crops, and 2. the feasibility with which they could be achieved. The results were then visually presented to the participants after each exercise, and they were given the opportunity to discuss the results, explain why they scored as they did, and whether any management approaches were missing. Ahead of the workshops our survey was assessed by the University of Reading School of Agriculture, Policy and Development ethical committee and given a favourable outcome (ref 1770D).

3.3 Evidence review

To highlight likely evidence gaps and identify data on the effects of management practices on OSR yield parameters we carried out a systematic literature review using the research database 'Web of Knowledge'.

3.3.1 Literature search

We developed a list of search terms aimed at identifying published literature which measured the effects of management approaches on OSR physiology and yield parameters. Ten separate searches were carried out using search terms to cover the management approaches considered during the workshops (Table 1.). Search terms were arranged in such a way as to optimise the search by including the crop OSR (and associated terms using 'or'), the management approaches (and associated terms using 'or') and target crop responses (physiology, yield and associated terms using 'or'). The total number of studies identified by each search was recorded and then sorted by relevance. The top 100 papers from each search were then reviewed for their relevance, potential for containing suitable data, and if so, stored in a database.

3.4 Developing a modelling and decision support framework

Farmers are responsible for making numerous decisions throughout the growing season, with varying impacts on crop production and associated outputs. Each decision can be dependent on several contributing factors, often relating to the outputs of previous decision, making the overall management of a crop exponentially complicated. To aid farmers in the process, Decision Support

Systems (DSS) are interactive systems (usually software based) that help users identify and solve problems and make decisions as part of developing an overall strategy (Damos, 2015). Most DSS are underpinned by models, developed from real data and validated in representative environments with input from end users. Models provide predictions based on a relationship between descriptive data and expected outcomes, but on their own do little to support decision making. A good DSS will enable the user to make effective decisions with confidence, and in full knowledge of the associated risks and assumptions (Jakku and Thorburn, 2010). They are never a replacement for grower experience or industry support but should add to other sources of information to improve decision-making. The target end users are normally growers and/or agricultural advisors, and most DSS are presented in very simple formats to encourage wider use. Simplification has a benefit in making DSS outputs readily accessible. However, it can create barriers to use where outcomes are perceived as untrustworthy due to a lack of transparency or sophistication. Conversely, if the system is too complex, its users may be put off by the time taken to provide the required inputs and interpret the outputs. DSS are most effective where they are used in tandem with supplementary information from peers and technical experts. This ensures that it is fit for the purpose and creates a network of informed users who trust and support the final system.

Input requirements for the models vary from relatively simple information, such as the timing of management activities (e.g. drilling date), to a complex integration of climate data, agronomic factors and pest observations. Interpretation of outputs can be straightforward, such as indicating whether or not a pest is likely to cause economic damage. Others however require a great deal of additional information and understanding, especially where the models are bound by assumptions about some of the factors (e.g. soil type, crop variety/health, availability of treatments etc.) that may not always apply to an individual case. Whatever the inputs and outputs, the associated assumptions and a summary description of the algorithm behind the outputs should ideally be available. Advanced systems may, however, combine multiple algorithms, requiring data on factors not available to the system or approximations derived from available data. These systems are inevitably difficult to summarise, but publication of their core principles encourages user engagement and improves uptake.

Within the literature search several models were defined, though few have suitable user interfaces, or the technical industry support needed to make them effective decision support systems. In this work, for each management approach identified and reviewed during the workshops (Table 1.), we have extracted key decisions and the associated parameters that are likely to be required by underlying models for useful DSS targeting a reduction in GHG emissions associated with oilseed rape. The result is a series of DSS that together form an overall climate smart oilseed rape production strategy.

4 Results

4.1 Expert workshop

Twelve researchers from the University of Reading and ADAS attended the expert workshop. They had a range of experience in sustainable crop production, including ecologists, agronomists, crop modellers and crop physiologists. When asked to list factors which are important determinants of oilseed physiology and yield, a range of factors emerged concerning many aspects of OSR production. Fertility management, crop establishment and pest management were listed often and considered key factors.

When experts were asked to score the 13 factors, ‘Optimise sowing’ emerged as the factor that could deliver the greatest benefit and was also considered highly feasible relative to other factors (Fig 2.). ‘Optimise soil nutrients’ and ‘Reduce weeds’ (through conventional means) were also considered both beneficial and feasible. ‘Improve soil structure’ was considered highly beneficial but relatively unfeasible compared to other factors. ‘Improve pollination’ (by wild insects) and ‘Reduce pathogens’ (through non-conventional means) were scored relatively low for both potential benefit and feasibility.

Fig 2. Distribution of factors based on their potential to deliver improved yield of oilseed rape and the feasibility with which they could be achieved. As scored by research experts at an online workshop.

After discussion with the research team, it was agreed that taking a scoring-based approach for potential benefit and feasibility was an appropriate way of identifying the best opportunities for reducing GHG emissions in OSR production. However, it was agreed that when working with farmers and agronomists, it would be necessary to consider specific management practices rather than broad factors.

4.2 Stakeholder Workshop

The farmers and agronomists who took part in the stakeholder workshop had a range of backgrounds and represented several organisations, and all have considerable experience in managing OSR. When asked to score the management approaches, overall, some management approaches emerged as more beneficial and feasible within the different categories (Fig 3.), including reducing tillage (or using no tillage), reducing insecticide to increase pollination, or employing pesticide thresholds. All approaches to optimise the crop canopy were considered highly beneficial and feasible. Participants' views on the potential benefit and feasibility of the different management approaches were more variable for some categories than others. For example, management approaches to manage the canopy or prevent pest outbreaks were highly clustered. By contrast, soil management approaches showed a large spread between approaches, with the use of windbreaks, irrigation or applying green manures scoring relatively low for potential benefit and feasibility. Specific feedback from attendees provided some critical additional information. For example, targeting sowing rates, sowing dates and particularly crop varieties to individual fields were considered practically very challenging and such an approach would be more feasible at the farm scale. Due to early sowing, creating a sterile seed bed for OSR was considered impractical, and due to legislation, there are many restrictions to the type and timing of organic manure application for OSR which would need to be overcome through policy change.

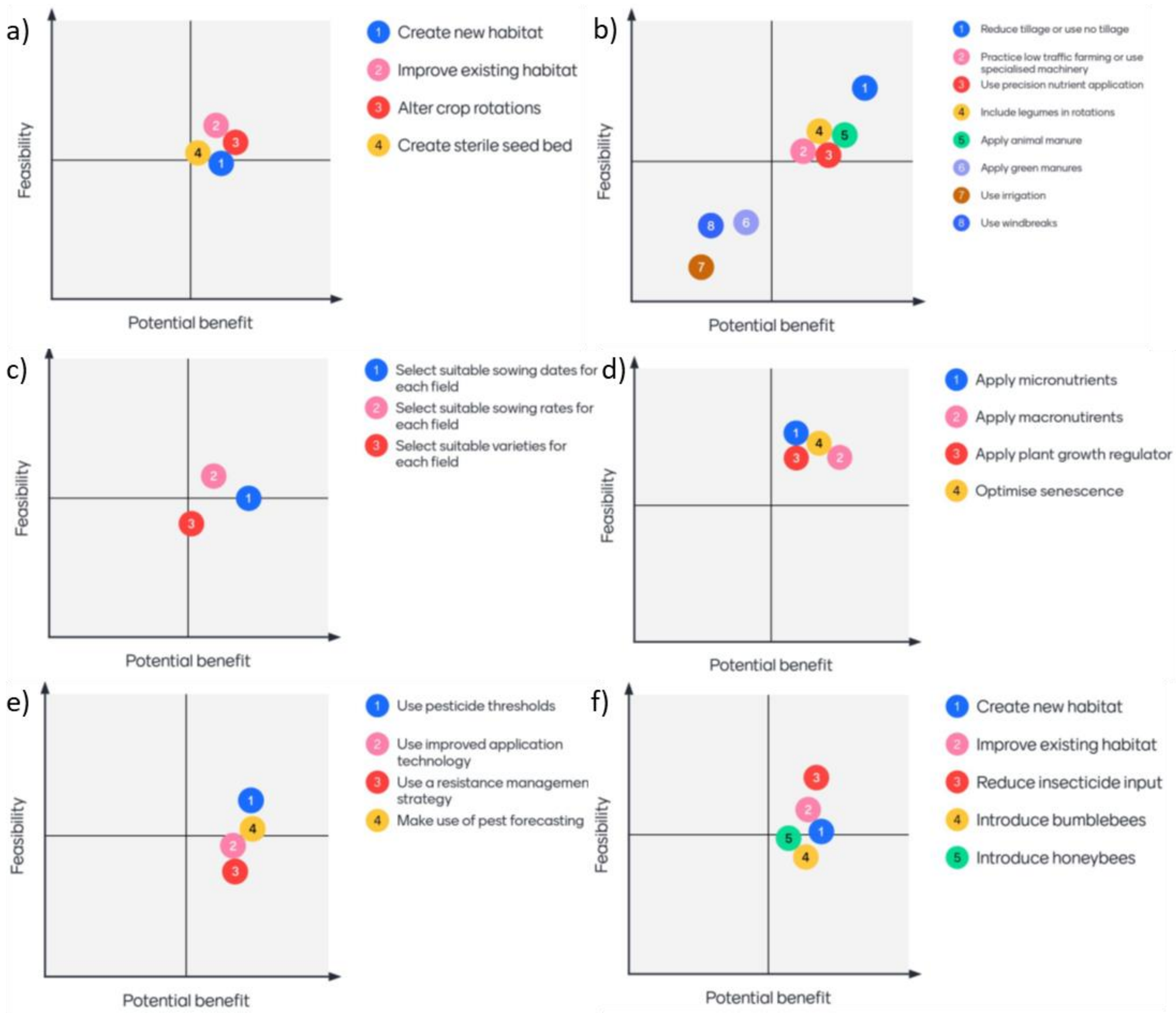

Fig 3. Distribution of management approaches based on their potential to deliver improved yield of oilseed rape and the feasibility with which they could be achieved, as scored by farmers and agronomists at an online workshop. Management approaches are divided into six categories based on when they are implemented in the growing cycle including a) Preventative pest management, b) Soil management, c) Crop establishment, d) Canopy management, e) Responsive pest management and f) Pollination.

4.3 Evidence review

A total of 57615 papers were identified during the literature search. The searches which generated the greatest number of papers were those associated with soil nutrient management, while research concerning crop canopy management appeared to have the fewest studies, at least based on the search terms used (Table 2.). After sorting papers by relevance and identifying those which contain suitable data to explore the effects of different management approaches on OSR physiological and yield responses, again the number of relevant studies varied between categories (Table 2.). With Establishment of the crop through sowing rate & density showing the greatest number, and

Establishment using different varieties providing the least. It is important to note that this may not be a full reflection of the weight of evidence available for each category or management approach because whether a study emerges and is considered relevant is an artifact of the search terms used. Our search is likely to reflect trends in overall evidence, how accessible it is, how much data is likely to be available and therefore possible evidence gaps. However, to accurately quantify this would require a full appraisal of all the studies turned up by the searches.

Factor	Total No. of Papers	Total relevant papers from 1st 100 titles	% of Top 100 Papers accessible	% of Top 100 Papers including data in figures or tables	% of Top 100 Papers with Raw data files available
Establishment (sowing date & density)	1459	59	34	34	0
Establishment (variety selection)	10589	8	4	4	0
Pest management (conventional & natural insect pest management)	7227	18	14	9	2
Pest management (conventional & natural disease management)	10625	25	19	17	0
Pest management (conventional & natural weed management)	5414	12	10	9	1
Soil management (nutrients)	15825	40	26	24	0
Soil management (structure)	2168	12	10	10	0
Soil management (moisture)	2526	31	23	22	0
Canopy management	812	19	10	10	1
Pollination (wild & managed insects)	970	24	21	20	5
Total papers	57615	248	171	159	9
% papers		24.8	17.1	15.9	0.9

Table 2. The number of papers concerning oilseed rape generated by a systematic search of the 'Web of Knowledge' using a collection of search terms for each factor. The number of relevant papers and the number which included data or associated databases is also shown.

4.4 Modelling and decision support framework

4.4.1 Decisions

Based on feedback from the workshop and the literature search, we have identified six categories based on when they are implemented in the growing cycle including a) Preventative pest management, b) Soil management, c) Crop establishment, d) Canopy management, e) Responsive pest management and f) Pollination. These represent critical decision points during oilseed rape production where improvements to management would enable farmers to optimise inputs while maintaining production, so reducing GHG emissions. For each decision point, one or more models need to be developed/revised, validated, and incorporated into a wider decision support system that makes them accessible and practical for use on farm. Below we identify potential models and associated DSS that would be beneficial to sustainable oilseed production.

A. Preventative pest management

DSS that identified plant mixes and associated management for non-crop habitat designed to promote natural enemies of crop pests, based on soil type, rotation, and area, would be beneficial (Ramsden *et al*. 2014). As well as supporting crop production, these non-crop areas can also act as carbon storage areas as they are designed to be left undisturbed for extended periods (Falloon, Powlson and Smith, 2004). Despite being widely present on arable farms there is little widely accessible support for optimal, location specific margin management, or the specific benefits to oilseed rape production and reduced GHG emission. In OptiSeed workshops, creation and improvements to non-crop habitats were seen as beneficial, and moderately feasible. Improved access to decision support systems for these (and associated) decisions would help improve the perceived feasibility. DSS that scores the suitability of oilseed as the next crop in rotation based on field history would also be beneficial to farmers. Oilseed rape is almost entirely grown as part of a rotation in the UK, however there is clear benefit that extending the period between brassica crops has benefits in reducing pest pressure and increasing crop performance. IOBC guidance (2019) recommends that cruciferous crops must not be grown more than one year in four, and sugar beet, sunflowers and soybeans should be avoided as a pre-crop.

Models/DSS for development

5 DSS to guide plant selection for, and management of non-crop habitats to promote natural enemies of oilseed pests.

6 DSS to guide suitability of field for oilseed crop, based on field history.

B. Soil management

Decisions associated with switching to reduced /no-tillage, low traffic farming, precision application technology, manure application and irrigation are cross-crop issues and so part of wider farm strategies. Strategic decision support systems are usually not model based, and more often require qualitative rather than quantitative input data to help guide users to the best approach for them (Damos 2015). Information about soil management practices should, however, be included as parameters in subsequent oilseed rape DSS, as they underpin many of the interactions between the crop and farm environment.

C. Crop establishment

The impact of soil preparation, drilling rates and dates are fundamental to the productivity and sustainability of oilseed rape cropping. Reduced tillage and optimal sowing has been shown to be an effective route to productive, low emissions crops (Saldukaite *et al.* 2022). Drilling date is a key consideration for oilseed rape production, and its influence on yield is well established (Lutman and

Dixon 1987). Drilling date is largely influenced by access to the land, limited by the previous crop and prioritisation of drilling other higher value crops, as well as efforts to minimise the impact of cabbage stem flea beetle migrating into crops. DSS based on a modelled prediction of establishment success and yield based on proposed drilling date, rate, soil preparations and pest pressures, would help farmers plan their autumn drilling strategy and/or subsequent management of the crop. This factor was identified by the 'expert' workshop as the most feasible and beneficial route to improved production. In the industry workshop it was also recognised as beneficial and feasible, and support systems for this would be welcome. Crop variety is another important consideration, and the AHDB recommended list already provides extensive guidance on oilseed varieties. In the industry workshop, there was some scepticism as to the practical benefits of improved variety (with the exception of step changes in resistance to high priority pests), partly because of the difficulties in identifying the best variety for the farm, and partly because subsequent management decisions are often made independent of variety. As new varieties appear regularly, it is difficult for DSS on later decisions to incorporate variety specific traits, however this would bring significant benefits in improving variety specific management. During the workshop it was also pointed out that farmers rarely manage specific fields according to individual needs, rather the best cross-farm approached was selected. This may result in decisions being made that are not optimal for all fields (e.g. where an individual field's conditions are very different from most other fields). Decision support that highlights where this may have very large impacts for productivity on individual fields may therefore be beneficial, however developers must work on the basis that outputs should account for cross-farm application rather than point location application. *Models/DSS for development*

- DSS with models predicting likelihood of successful establishment and associated yield potential based on soil preparations, variety, drilling date, drilling rate, and estimated pest pressure.

D. Canopy management

Improved nutrient and PGR application is an area of great potential for efficiencies in oilseed production. Various strategies are used, largely based on growth stage and crop condition (Rathke, Behrens and Diepenbrock, 2006), and increasingly tissue sampling is being used to guide targeted nutrient applications. As over application of nitrogen is a key contributor to GHG emissions associated with oilseed rape, improved decision support here would have a positive impact. While not addressed specifically in the workshop, optimal oil content is a further aspect to consider when reviewing management approaches, as this is more directly associated with crop value than net yield. Oil content can be increased by extending the period of seed filling and can be reduced through excessive nitrogen application (Berry and Spink, 2006). DSS based on modelled response of oilseed to nutrient application are highly valuable to improving sustainable production. Improved targeted applications would increase production efficiency and reduce excess application – a key factor in

GHG emissions. Workshop feedback suggested that improved support in this area would be both beneficial and feasible.

Models/DSS for development

- DSS indicating likely benefit(s) of micro/macro nutrient application at a given application timing, based on current growth stage, climate, and nutritional status.

E. Responsive pest management

Improvements to responsive pest management were seen as beneficial in the workshop, especially where access to up-to-date economic thresholds could be increased. Pest forecasting, and associated predictions on the impact of specific actions, were seen as beneficial and moderately feasible. While improved application technology and resistance management strategies were seen as beneficial, they were not considered as easy to implement. In all cases, DSS would help increase the perceived feasibility of these approaches, especially improved models and thresholds for the management of cabbage stem flea beetle and canopy diseases. While many models already exist, access to and uptake of these systems is low (Ramsden *et al*, 2017). A key gap remains on the ability to predict with confidence the migration of cabbage stem flea beetle into the crops in early autumn.

Models/DSS for development

- DSS based on models forecasting CSFB migration.
- DSS based on models predicting larval load in plants over winter, and potential benefit of mowing the crop ahead of stem extension.

F. Pollination

Feedback from the workshop indicated that reducing insecticide inputs was the most feasible option for promoting pollinators, followed by improvement/creation of habitat for pollinators. The introduction of honeybees and bumblebees was seen as marginally beneficial but not very feasible. Decision support to improve pest management and reduce insecticide application is a clear priority, alongside additional support in managing alternative habitats. DSS developed for habitat management outlined above would be beneficial for pollinator management. In addition, models that indicate periods of high risk to pollinators by insecticide applications would be beneficial.

Models/DSS for development

- DSS based on models predicting periods of high pollinator activity, when pesticide applications should be avoided.
- DSS to guide plant selection for, and management of non-crop habitats to promote pollinators of oilseed pests.

4.4.2 Parameters

During model development, a range of potential parameters may be tested to identify those that significantly influence outcomes; the most common parameters used in agronomic decision support (as presented in Table 3) are outlined below. Some of these can be collected remotely (e.g. climate data), but others rely on farmer inputs (e.g. previous crop).

Previous crop(s)

The crops grown immediately before oilseed rape, and the total years since oilseed rape was last grown at that location, are important factors in understanding the productivity and input requirements. Wider rotations reduce the build-up of key pests (e.g. cabbage stem flea beetle, and clubroot), but rotation also plays a role in soil condition (e.g. if legumes have been grown recently), abundance of beneficial insects (e.g. more diverse rotations help to promote the diversity and abundance of natural enemies of crop pests and pollinators).

Climate data

Rainfall, air/soil temperature, wind speed/direction and solar radiation (and associated derivations such as humidity, leaf wetness, day degrees etc) are widely used in crop models.

Historical pest pressure

The previous presence/abundance of a pest in the current or previous crop or surrounding fields.

Soil type

Soil type has various impacts on crop production, largely associated with water holding capacity and nutrition status.

Variety

Different varieties of oilseed rape provide a range of benefits, tolerance to different conditions and pest pressures. Each variety has associated yield potentials and requires bespoke management to achieve best results.

Plants/m^2

Related to drilling rate, the number of plants per area is an important metric as it indicates the total number of individual plants (that may be damaged by pests). Several other metrics are related to this factor, as branching (and so number and size of pods) is related to plant density.

Growth stage

Growth stage is often used as a proxy for other factors (e.g. crop’s ability to tolerate particular pests, or a crop’s nutritional requirements). The period between defined growth stages is also indicative of key production periods, e.g. oil content is increased where seed filling is extended.

Field size

Field size gives an indication of cropping intensity and of the availability of non-crop resources. This can be used to assess potential pest risks and/or impact of beneficial invertebrates (natural enemies of crop pests or pollinators).

Landscape intensity

The ratio of crop to non-crop habitat can be used as a proxy for the existing resource availability to beneficial invertebrates. In simple landscapes dominated by cropping, few additional resources are available and beneficial species are unlikely to be well supported.

Biomass or biomass proxy

Green Area Index (GAI) and other biomass assessments can be a relatively straightforward metric to collect in field, and can be used as an input to indicate the current crop condition.

Drilling Date and Rate

The date the crop went into the ground is often used as a start point for models, to identify potential periods of vulnerability to pests/climatic conditions, and associated treatment dates. Drilling date is also strongly related to yield potential. Drilling rate is less predictive of yield, but influences plants/m^2 associated with crop performance.

Soil and Crop nutrition status

Where decisions relate to application of macro/micronutrients, fertilisers and plant growth regulators, the current availability of nutrients in the soil, and presence in plant tissues can be used to add inputs according to need.

Non-crop habitat condition

Where existing non-crop habitats (grass margins, flowering margins, hedgerows, etc) can be improved, the current status needs to be assessed (e.g. species presence and distribution).

Expected end value

The expected end value of the crop is an important consideration for farmers, but seldom included in models. More often, a historic average value is used (if at all), which may not reflect the specific value to the farmer.

Predicted yield

Yield predictions can be made at various points of the growing season, based on hypothetical maximal yield potential (e.g. the YEN yield potential model), or on specific crop metrics. Yield predictions, along with expected end value, provide an indication of the benefit of applying additional inputs to the crop. Currently yield predictions are infrequently incorporated into oilseed rape decision support systems.

Numerous additional parameters can be (and are) collected by farmers; over 80 separate metrics are collected within the Oilseed Yield Enhancement network, however this puts increasing workload on farmers and results in increasingly patchy datasets that are more complicated to use for analysis and modelling. Preventative pest management, soil management and crop establishment are largely addressed early in the growing season and are associated with few parameters (Fig. 4). Some parameters can be collected remotely without the need for farmers to input data, however the majority require the farmer to provide detail on their crop in order to run the associated models (Table 3). Data entry is a significant barrier to the implementation of DSS, as it is time consuming and often repetitive – with multiple systems requiring the same data to be entered. This can be overcome where DSS can extract agronomic data from farm management information software, and where systems collect and store data centrally to be used in individual models as required.

Figure 4: Summary of key parameters likely to be associated with DSS/models for each of the six categories of management approaches.

Table 3: Summary of the primary and secondary sources of data for parameters likely to be required for oilseed DSS/models.

Parameter	Primary source(s)	Secondary source(s)
Previous crop(s)	Farmer provided data	Link to Farm Management Information Software
Climate data	Remote collected (e.g. Met Office data)	On farm weather station Local weather station
Historical pest pressure	Farmer provided data	Based on historical forecasts and regional recordings
Soil type	Farmer provided data	National mapping
Variety	Farmer provided data	-
Plants/m^2	Farmer provided data	-
Growth stage	Farmer provided data	Regional average in representative crops
Field size	Farmer provided data	GIS analysis
Landscape intensity	GIS analysis	-
Biomass or biomass proxy	Farmer provided data	Satellite imagery
Crop nutrition status	Farmer provided data	Link to results from lab analysis
Drilling Date and Rate	Farmer provided data	-
Non-crop habitat condition	Farmer provided data	Satellite imagery
Soil nutrition status	Farmer provided data	Link to results from lab analysis
Expected end value	Farmer provided data	National data
Predicted yield	Model based on above data	Variety specific estimates

4.4.3 Conceptual strategy for sustainable oilseed rape production

Based on the DSS/models identified in section 4.4.2, a conceptual strategic model has been outlined in Fig 5. Development and uptake of this series of systems during oilseed production, alongside the use of existing systems, would support reducing inputs and associated GHG emissions. This approach promotes an integrated approach to management across the various elements of crop management.

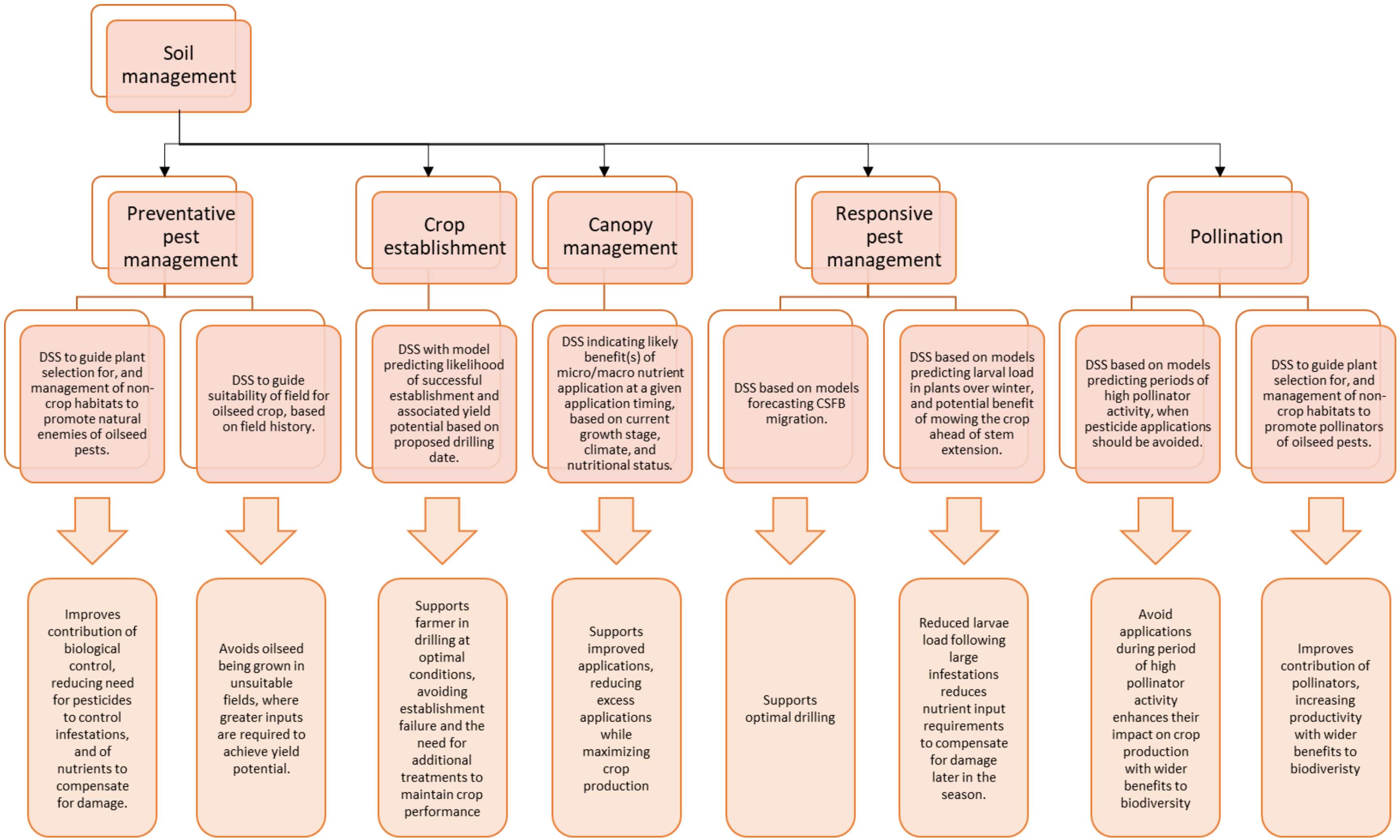

Figure 5: Conceptual strategy for sustainable oilseed rape production

5 Discussion

Our research project acknowledges the potential for reducing GHG emissions from OSR production, particularly through nutrient management which currently contributes the majority of GHG. We show that this could be achieved through a number of approaches which consider a broad spectrum of management approaches employed at various stages of crop production, including adapting associated non-crop habitats, soil characteristics, crop physiology and wider biodiversity (e.g. pollinators and natural enemies). Through interactions with research experts and practitioners (farmers and agronomists) we have been able to highlight management approaches, the optimisation of which represent the best opportunity to improve OSR production from both a yield and reduced GHG perspective. These include utilising alternative nutrient sources including manures and growing legumes in rotation, promoting biodiversity-based ecosystem services such as pollination and natural pest control through improving existing non-crop habitats, employing pest management thresholds, and effectively managing the crop canopy. We show that many of these management approaches and their effects on OSR are well researched, particularly pest control and nutrient management, while others are less extensively studied (e.g. pollination and canopy management). While a number of excellent support networks/DSS exist, there is little cross-topic coordination. This creates a barrier to integrating oilseed management across the growing season, and so each decision is largely made independently of other factors; for example, decisions about crop canopy management are largely independent of decisions about preventative pest management. This is logical at face value, where decisions are made to prioritise logistical considerations and maximise yield. However as crops are grown increasingly with a view to the long-term sustainability of the overall system, greater attention to the full series of decisions and their interactions is required. This moves production away from an input-heavy approach, but requires a wider and deeper knowledge of the biological, agronomic and socioeconomic drivers of crop production. Our initial schematic highlights some key decision points with common parameters that should be considered throughout the season, and identifies a selection of priorities for future DSS development.

Our project has shown that not all management approaches are equal in terms of their potential to meet the challenge of NET ZERO, and some approaches have the potential to deliver greater benefits whilst also being practically more feasible. For example, we found that while creating new habitats and adapting existing non-crop habitats were considered equally beneficial, from a feasibility perspective improving the quality of existing habitats was preferred. Given the quality of non-crop habitats such as hedgerows and field margins influences the extent to which they may deliver benefits (Garratt *et al.* 2017; Albrecht *et al.* 2020), focusing research and support on improving habitat quality may provide the greatest opportunity, although currently we find a lack of research and DSS in this area. In terms of soil management reducing tillage intensity was considered highly beneficial and feasible, and while it is encouraging this is now a common practice, continued support to mitigate the challenges associated with such practices is required (Fried *et al*. 2015). By contrast, and as expected, using irrigation and establishment of windbreaks to manage soil moisture was not considered beneficial or feasible in a UK context. All aspects of canopy management including foliar applied fertilisers and growth regulators were considered beneficial and feasible, and are well known as an important determinant of GAI and therefore yield (AHDB). Interestingly the literature search generated fewer studies exploring canopy management in OSR than for other management factors considered, although it likely represents a narrower research field than other approaches, pest management for example. Modifying pesticide inputs to protect both pollinators and natural enemies for the benefits they provide in terms of production (Dainese *et al.* 2019, Stanley *et al*. 2015, Garratt *et al*. 2014), particularly through use of thresholds, was considered a beneficial and feasible approach. This should therefore remain a priority for both research (Ramsden et al. 2017) and development of DSS, particularly for key pests in OSR like cabbage stem flea beetle.

6 Conclusion

That the feasibility and potential benefits of different management adaptions vary is clear, and the available evidence and associated DSS for management approaches are widespread, if unbalanced in terms of their availability. There is however currently a gap, or opportunity to link these separate components and DSS up to provide a more integrated support system which acknowledges, and takes into account, the interrelatedness of these different factors. We have been able to highlight where DSS is needed (e.g. improving quality of habitats, managing CSFB, use of pesticide thresholds) and in some cases good support already exists. However, we need to test the extent to which taking a whole system approach can deliver improved benefits in terms of GHG reduction and identify where the key management challenges are. This could be done through targeted field trials comparing packages of approaches, or by utilising existing grower networks and implementing altered practices in a controlled way, and measuring input use and yield responses. There is also a need to relate specific decision points to the wider crop production context, and improve decision support systems around non-crop habitat management that would be highly beneficial.

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