# SUPPLEMENTARY MATERIAL

***Appendix 1****, Guides for the semi-structured interviews*

**Interviews in 2018**

*Introduction*

* Researcher reminds about the purpose of the on-farm experiments: practical tests in farm-specific conditions of cultivation practices that can enable increased grain legume production
* Researcher explains purpose of the interview: document farmers’ perceptions of the on-farm experiments, to be able to identify knowledge gains from the collaborative approach

*Questions*

* General description of the farm: size and location, farming system, overall soil type/s
* Have you previously cultivated grain legumes? Which, and for how many years? Why do you cultivate grain legumes?
* From where do you obtain information about grain legume cultivation? Same source/s as for information about other cultivation of crops?
* General description of the on-farm experiment/s conducted within this project: soil type of the chosen field/s, soil preparation before sowing, choice of crop/s and variety/ies, crop management (*e.g.*weed control, fertilization), experimental treatments, other remarks/observations. Why did you choose this/these field/s for the experiment/s?
* What are the reasons why you chose the practices that are tested in your experiment/s this year? From where did you obtain information about these practices? Are they different for what you usually apply in grain legume cultivation? How? From where do you usually obtain information about cultivation practices?
* What do you think about the observations and measurements that we (researchers) have suggested for the experiment (crop plant density, pod density, spike density (intercropped cereal), crop height, crop biomass, crop lodging, visual estimation of weed pressure, main weed species and total weed biomass)? Anything you would like to add?

**Interviews in 2019**

*Introduction*

* Researcher reminds about the purpose of the project in which on-farm experiments is one part: stimulate an increased production and use (as food) of grain legumes in Sweden.
* Researcher explains the purpose of the interview: discuss last year’s experiment/s and how it/they relate/s to the crop/s and cultivation practice/s that are tested on your farm this year; discuss and agree on how to observe and evaluate your experiment/s; follow up and complement information about knowledge gains through the collaborative approach.

*Questions*

* How did you hear about this group, and what motivated you to join?
* Can you summarize the experiment/s that you conducted on your farm last year (purpose, performance and main results/conclusions)?
* Was last year’s experiment/s linked to other experiments or tests that you had performed previously? How novel was last year’s experiment/s to you?
* Last year’s drought affected the experiments, did you do anything to control for it or adapt to it? What have you learnt in case similar drought occurs in the future?
* What are your thoughts about knowledge gains from last year’s experiment/s? Anything you think should have been done differently in the design, management and evaluation of the experiment/s, in order to learn more?
* How did you chose the location and size of last year’s experiment/s? Would you have managed the experiment/s differently if the experimental surface had been larger?
* How has last year’s experiment/s influenced the design (treatments) and management of this year’s experiment/s?
* What are your thought about experiments conducted in research, *i.e.*typically with small plots, several treatments and replications? Have you looked at results from research experiments, and do you find them useful? Why/why not?
* What were your thoughts about the researchers’ suggestions for on-farm experiments, sent to the farmer group in March 2018?
* Do you think that being part of this farmer group and the collaboration with researchers change the way that you perform experiments? How? Will you experiment more and/or differently than before joining the group?
* How important are all the measurements that we /researchers are doing in the on-farm experiments?
* Which observations and measurements do you need to decide if you will apply the practice/s in larger scale?
* Do you think that the on-farm experiments contribute to/fulfill the purpose of the project (stimulate an increased production and use (as food) of grain legumes in Sweden)? How?
* Do you already now have plans/ideas for experiments with grain legumes on your farm next year?

|  |
| --- |
| ***Table S1.*** *Timeline for activities (workshops, farm visits and other communications, observations and measurements) in the researcher-farmer collaboration.* |
| **Date** | **Action** | **Participants** | **Content** |
| 08 Nov 2017 | First workshop (recorded) | 8 farmers, 2 researchers, representatives from food companies participating in the research project | Discussing the overall aims and motivation for joining the farmer group, expressing specific interests and questions in relation to the overall goal of producing more grain legumes, discussing legume crops of largest interest. |
| 06 Feb 2018 | Second workshop | 7 farmers , 1 researcher, 1 food company representative  | Discussing relevant knowledge gaps and suitable on-farm experiments. |
| 14 March 2018 | Follow-up email from researcher to farmers | Email to 11 farmers | List of suggestions for on-farm experiments (supplementary material), based on knowledge gaps, farmers’ interests and expected interest from food companies. Proposed protocol for field observations in the experiments. |
| March-May 2018 | Refinement of plans for experiments, measurements and observations | 9 farmers, 4 researchers | Researcher-farmer communication via email and phone, to refine plans for the on-farm experiments, agree on crops and experimental treatments, assist (by researchers) in seed acquisition, agree on timing of observations and measurements. Researcher meetings to plan data collection activities during the growing season: developing an interview guide and a protocol for observations and measurements. |
| June 2018 | Farm visits, interviews and field observations (recorded) | Two researchers interviewing 9 farmers & observing 9 experiments | Semi-structured interviews based on Catalogna & Navarrete (2016) framework. Observations according to protocol (weed abundance, crop plant height, plant density and lodging). Photographic documentation. |
| June-Aug 2018 | Field observations and follow-up interviews (recorded) | 2 researchers separately observing 9 experiments and performing 7 follow-up interviews, | Interviews concerning farmers’ agronomic practices performed in the experiments, trial evaluations and explications of results. Researchers’ observations and measurements according to protocol (crop plant density, height and lodging, crop biomass, weed abundance, weed biomass). Photographic documentation. |
| 09 Aug 2018 | Summary of the first year’s experiments, planning the next activity | 11 farmers, 2 researchers | Summary of results with request for feedback and corrections sent individually to each farmer who had conducted experiments, information to the whole group about upcoming workshop. Researchers planning upcoming workshop including follow-up questions adapted to the analytical framework. |
| 30 Nov 2018 | Third workshop (recorded) | 6 farmers, 3 researchers | Presentation of results, confirmation of accuracy by farmers, discussion and interpretation of results. Initial planning of next season’s experiments. Discussion on sustainability indicators. |
| Feb-May 2019 | Planning the second year’s experiments, measurements and observations | 2 researchers, 9 farmers, | Researcher-farmer communication via email and phone, to agree on crops and experimental treatments, assist (by researchers) in seed acquisition, agree on timing of observations and measurements. Researcher meetings to plan data collection activities during the growing season. |
| July 2019 | Interviews (recorded) | 2 researchers, 5 farmers | Follow-up interviews: discussion of last year’s experiment, questions on the experimentation process, visit to ongoing experiments: links with last year (topic and methods), planning of sampling and measurements to be conducted by researchers.  |
| Aug 2019 | Field observations | 2 researchers, 4 farmers | Sampling and measurements in the on-farm experiments, performed by researchers: crop plant density, height and lodging, crop biomass, weed abundance, weed biomass |
| Feb 2020 | Fourth workshop (recorded) | 2 researchers, 6 farmers | Presentation of the experiments by each farmer, presentation of the results based on the data collected by the researchers, questions to the farmers about their perception of the collaboration with researchers on their experiments. |

***Table S2.*** *Overview of the researchers’ suggestions for on-farm experiments, sent to the farmer group in March 2018.*

|  |  |  |
| --- | --- | --- |
| **Crop** | **Motivation to perform experiments** | **Suggested types of experiments** |
| Faba bean | Well-known crop, many farmers have positive experience, potential to increase production. Potential to adjust practices to improve efficiency and profitability of the production, and to optimise the pre-crop value of the crop. | Different methods for weed control: weed harrowing vs hoeing after sowing with narrow vs wide row spacing. Different sowing densities or sowing dates, different crop varieties. Follow up by visual observations of weed abundance and measurements of crop and weed biomass and crop yield. Undersowing a cover crop, either at crop establishment or in the growing crop, to reduce the risk of N losses and improve the pre-crop effect, possibly also reduce weeds. Intercropping with a cereal to reduce weeds and reduce the risk of N losses. Include faba bean sole crop in the same field for comparison with cover crop or intercropping. Follow up by observations or measurements of weeds and measurements of crop yield, including yield of subsequent crop. |
| Grey pea | Relatively unknown crop, increasing interest from farmers, food industry and consumers. Important to define practices that reduce the risk of bird damages or lodging. | Intercropping with a cereal or with faba bean, or a three-species intercrop (grey pea + faba bean + cereal) to reduce lodging, possibly also to reduce bird damage. Comparison of different seed proportions and densities. Follow up by visual observations and measurements of lodging, weed abundance, bird damage and crop yield. |
| Lupin | Relatively unknown crop, increasing interest from farmers, food industry and consumers. Important to define practices that reduce problems with weeds. | Different methods for weed control, intercropping with a cereal (see suggestions for faba bean). |
| Lentil | Relatively unknown crop, increasing interest from farmers, food industry and consumers. Important to define practices that reduce problems with weeds and lodging. | Intercropping with a cereal to reduce weeds and lodging, comparison with lentil sole crop and different intercrop proportions. |
| Common bean | Relatively unknown crop, increasing interest from farmers, food industry and consumers. Important to define suitable growth conditions and technical management at harvest. | Pioneer experiments to define conditions and practices that makes the production feasible in a region where the crop is currently not grown. |
|  | Any observation or experience from testing own ideas for new or adapted practices in grain legume cultivation is valuable to note and share in the group. | Depends on the crop and practice that the farmer is testing; encouragement to take notes of observations or measurements in any type of comparison, to stimulate discussion of ideas and interpretations with the researchers and with other farmers. |

***Table S3.*** *Brief description of all experiments performed.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Farmer, year, crop** | **Theme** | **Aim** | **Treatments** | **Unexpected outcomes** | **Conclusions** |
| A,2018,Lentil | Intercrop, relatively new crop | Learn about lentil cultivation. Test intercropping as a way to grow cereals in lentil fields.  | Intercropping lentil and spelt with two spelt densities, comparison with both sole crops. | Experiment stopped: ploughed down because weeds took over. Only a small area of lentil sole crop was kept. | Spelt eaten by birds; very high weed pressure. Need to establish lentil in better conditions (choice and preparation of the field). |
| A,2019,Lentil  | Intercrop, relatively new crop | Learn more about lentil cultivation: find a suitable position in the rotation for the lentil-cereal intercrop. Adjust the cereal sowing density. Find a way to prevent bird damage to cereals. | Intercropping lentil and a spring wheat landrace, with two wheat densities, comparison with wheat sole crop. | Practically difficult to apply the target sowing densities. Increasing the density of the cereal led to decreased lentil sowing density, which was not the objective. | Relatively successful crop that could be harvested, but impossible to separate the seeds of the two species.  |
|  A,2019,Lentil | Intercrop, relatively new crop | Learn more about lentil cultivation: find a suitable position in the rotation for the lentil-cereal intercrop. Adjust the cereal sowing density. Find a way to prevent bird damage to cereals. | Intercropping lentil and spring emmer with two emmer densities, comparison with lentil sole crop | Practically difficult to apply the target sowing densities. Increasing the density of the cereal led to decreased lentil sowing density, which was not the objective. | Increasing cereal density led to a reduction in weed biomass. Successful crop, sorting the seeds was easy. Successful in direct sales of lentils at markets and farm shop.  |
| B,2018,Grey pea | New crop, intercrop | Learn about cultivation of grey pea, using the intercropped oats to control weeds.  | Grey pea sole crop, the same treatment on the whole field | Practical issues prevented trying intercrop with oats (lack of seeds) and undersown grass (drought). | Low yields due to a combination of drought, bird damage at establishment and pre-harvest, weed competition. Maybe grow faba bean or common bean instead? Will grow grey pea again in a normal year + try if intercropping is helpful against birds.  |
| B,2019,Grey pea | Intercrop, relatively new crop | Repeating previous year’s experiment with the aim to achieve a successful intercrop. | Intercropping grey pea and oat, the same treatment on the whole field. | Lower plant density of the grey pea than expected, due to bird damage. | Not a feasible crop on the farm, too large problems with birds. Not likely to try grey pea again. |
| C,2018,Faba bean | Sowing design  | Test sowing in narrow rows as a way to reduce the need for mechanical weeding.  | Faba bean, row width 12 ("narrow") vs current practice: 50 cm ("wide") and harrowing.  | Drought prevented sowing a catch crop with a third weeding in "wide". | Visually, less weeds in "wide" but the biomass measurements showed no difference. Higher faba bean plants in "wide", but higher number of plants and pods/m2 in "narrow". "Narrow" looked more affected by drought. |
| C,2019,Lentil  | Relatively new crop, variety, sowing density, mechanical weeding | Demonstration plots to disseminate information on cropping practices for organic lentil cultivation. | On one lentil variety: sole crop, intercrop with oats, three mechanical weeding intensities. A new lentil variety intercropped with oats in the same field. |  | Intercropping prevented lentil lodging (not novel), oats slightly reduced lentil biomass and significantly reduced weed biomass, combining mechanical weeding and intercropping gave the lowest biomass. The new lentil variety had late and uneven maturity. |
| D,2018,Austrian winter pea | Intercrop, new crop | Learn about winter pea cultivation, test it with triticale to reduce lodging and weed growth. | Autumn pea + triticale, the same treatment in the whole field, variation in clay content within the field. | Pea thrives much better in the heavier part of the field. | Low yields due to drought, intercropping secured harvest. The soil properties determined the balance between the two species across the field. |
| D,2018,Yellow pea | Establish-ment of cover crop | Establishing a clover-grass cover in yellow pea in drought. | Clover-grass undersown in pea, the same treatment in the whole field. |  | The practice allowed successful establishment of the cover crop. Deep sowing (5 cm) was a good strategy in case of drought. |
| D,2019,Austrian winter pea  | Intercrop, relatively new crop | Learn more about winter pea cultivation, test intercropping with rye to reduce lodging and weed growth. | Intercropping autumn pea and rye, the same treatment in the whole field. |  | Confirmation that intercropping is a successful strategy for winter grey pea, but disease infestation in rye.  |
| E,2018,Faba bean | Soil tillage vs. direct sowing | Test extra tillage at establishment of preceding cover crop to prevent perennial weeds from entering the field via the edges. | Direct sowing vs. shallow tillage in part of the field edges when sowing rye cover crop in autumn before direct sowing of faba bean in spring.  | The extra tillage made the soil uneven, leading to lower emergence of the cover crop (rye). | Weed pressure in the faba bean was higher where rye was sown after tillage. The extra tillage in the sides was not efficient in stopping perennial weeds. Herbicides were good enough to keep the sides clear. Faba bean did better in heavier soil (more water). |
| E,2019,Lentil  | New crop, varieties, inter-cropping | Learn about lentil cultivation (first time), choice of variety and testing intercropping with faba bean.  | Lentil sole crop, two varieties, one variety intercropped with faba bean.  | Choosing to establish the lentil experiment inside a faba bean field that matured later than lentils led to delayed lentil harvest. Difficulty in sorting lentils and faba beans because of broken faba bean seeds. | Successful lentil crop for both varieties, difficult harvest and spilled seeds because of delayed harvesting time and lodging (IC and SC), some progress in finding a market to sell conventionally-grown lentils. Will try intercropping lentil with a cereal instead of faba bean. |
| E,2019,Faba bean  | Effect of preceding cover crop | Evaluate different cover crops before faba bean and their termination strategies. | Faba bean after rye cover crop vs. after species mixture cover crop. Terminating cover crop with glyphosate in November vs. winter-killed (the 2 factors crossed). |  | The faba bean crop was not sensitive to differences in preceding cover crop. |
| F,2018,Lentil | Intercrop | Learn more about lentil cultivation, evaluate the relevance of intercropping. | Intercropping of lentil and oat, comparison with lentil sole crop. |  | Higher weed biomass and lodging in the lentil sole crops than intercrops, according to data from researchers. From the farmer's point of view, the lentil sole crop was also satisfactory. |
| F,2019,Lentil  | Intercrop, choice of variety | Learn more about lentil cultivation, test a new variety, evaluate the relevance of intercropping. | Intercropping of lentil and oat, comparison with lentil sole crop, 2 lentil varieties. | Was planning to test different companion crops but did not sow/emerge because of the dry soil. | No difference between the lentil varieties except for the oat biomass in intercrop. Intercropping did not have a strong effect on weed biomass. |
| G,2018,Faba bean | Establish-ment and weed control | Test the possibility to grow faba bean without tillage and without herbicide or pesticide (EFA, Ecological Focus Area). | Common practices (disc cultivation at sowing, 2 herbicides including glyphosate before emergence), EFA (no tillage, glyphosate before emergence, no chemicals after emergence). | Would have liked to sow more densely and deeper. | Lower faba bean height in EFA in June, much more weeds in EFA light soil, no difference in levels later on. EFA faba bean was rather satisfactory but without the extreme drought common practices might have yielded more than EFA. |
| G,2019, yellow pea | New crop, new buyer | Test the possibility to grow yellow pea for human consumption. | Yellow pea, the same treatment in the whole field. |  | Successful crop, relatively easy to produce but need to handle transportation to buyer. |
| H,2018,Faba bean | Mechanical weeding, sowing design + date  | Test mechanical weeding to replace an herbicide.  | Faba bean, 2 row widths (narrow and wide), two varieties, later sowing and different variety in “narrow”, no control with herbicide. Treatment "narrow" not followed by researchers because not comparable. |  | Early sowing was risky but gave a good result. Aphid damage in a corner with soil compaction. In treatment “wide”, volunteer oilseed rape plants in the rows could not be controlled by hoeing.  |
| I,2018,Yellow pea | New crop | Test the possibility to grow yellow pea for human consumption. | Yellow pea, the same treatment in the whole field. |  | High weed pressure, pea developed well despite damages by pea weevil (*Sitona)*. Low yield due to drought, would have needed irrigation. Successful contract with buyer for human consumption. |
| I,2019, Yellow pea | New crop, new buyer | Test the possibility to grow yellow pea for human consumption. | Yellow pea, the same treatment in the whole field. |  | Successful crop, relatively easy to produce but need to handle transportation to buyer. |

|  |
| --- |
| ***Table S4.****Examples of on-farm experiments in 2018 and 2019 at two farms, described in the framework adopted from Catalogna*et al*. (2018)* 1.  |
|   | **Design**  | **Management**  | **Evaluation**  |
| Year  | Objective  | Link to previous experimental situations  | Novelty  | Choice of location and size  | No. of treat-ments  | Progress, unexpected events  | Information collection  | Feasibility of post-harvest steps  | Achievement of the goal  | Discussion of the results  |
| F A R M E R    A |
| 2018  | Trying anew orrelatively new crop  | Solve a technical or agronomic problem due to a previously experimented practice to improve its feasibility  | New logic and new practice   | 4 plots on 1 ha  |  4   | Interruption due to weedproblems  | Information on the crops and agroecosystem  | No harvest  | Results do not achieve the farmer’s goals  | Unexpected technical difficulties and possible alternatives are discussed, cropping conditions responsible for the results are discussed.  |
| 2019  | Trying anew orrelatively new crop  | Solve a technical or agronomic problem due to a previously experimented practice to improve its feasibility  | Similar practice to what the farmer already applied  | 7 plots in total, on 2 fields of 1 ha each  |  7   | No change  | Information on the crops and agroecosystem  | All post-harvest steps considered an important part of the experiment   | Results do not achieve allfarmer’s goals  | Unexpected technical difficulties and possible alternatives are discussed, cropping conditions responsible for the results are discussed.  |
| F A R M E R    E |
| 2018  | Solve an agronomicproblem   | Solve a technical or agronomic problem due to a previously experimented practice to improve its feasibility  | Similar practice to what the farmer already applied  | 1 plot of ~100 m2 vs. the rest of the field  | 2   | No change  | Information on the crops and agroecosystem  | No post-harvest step considered an important part of the experiment   | Results do not achieve the farmer’s goals  | Ex-post hypothesis on agroecological processes is found to interpret the results.  |
| 2019  | Trying a new or relatively new crop  | No linkage with previous experimental situations  | New logic and new practice   | 3 plots on 1 ha  | 3  | No change  | Information on the crops and agroecosystem  | All post-harvest steps considered an important part of the experiment   | Results achieve all farmer'sgoals  | Unexpected technical difficulties and possible alternatives are discussed, cropping conditions responsible for the results are discussed.  |
| 2019  | Improve agro-ecosystem functioning    | Improve the agroecological processes mobilised with a previously experimented practice  | Similar practice to what the farmer already applied  | 4 plots on 30 ha   | 4  | No change  | Information on the crops and agroecosystem  | No post-harvest step considered an important part of the experiment | Results do not achieve all farmer’s goals  | No discussion of the results.   |

1 The following changes were made to the framework for the purpose of our study:

• The modality ‘trying a new or relatively new crop’ was added under the variable ‘objective’ (Design stage).

• The variable ‘spatial scale’ (Design stage) was replaced by ‘choice of location and size’, to make it possible to describe how the experiment was placed in the farm/field and why, along with information about the size of the experiment.

• The variable ‘simultaneous comparison’ (Design stage) was replaced by ‘number of treatments’ (essentially the same information, only named differently).

• We grouped the information collected on the set-up, crops, agroecosystem and work (originally four separate variables) into one variable: ‘information collection’.

• The variable ‘feasibility of post-harvest steps’ was added under the Management stage. Post-harvest steps include drying, sorting/cleaning, transporting/storing and selling the crop. This new variable contained four modalities: ‘all’, ‘some’ or ‘no post-harvest steps considered an important part of the experiment’, and ‘no harvest’.

• The variable ‘discoveries’ (Evaluation stage) was not used; this type of information was found to fit better in the variables ‘progress’ (which included information about unexpected events) or ‘discussion of the results.