PROJECT TITLE AND PROJECT NUMBER

FINAL REPORT The Swedish Farmers' Foundation for Agricultural Research "Winter wheat reaches new heights - a knowledge and problem inventory" H1233156-K00

THE REPORT'S AUTHORS

Helena Elmquist and others. Text and conclusions drawn from the book "*Winter Wheat Reaches New Heights*", which has many authors. To download the entire book and see a list of all authors, visit www.odlingibalans.com

BACKGROUND

Winter wheat is an important crop

Winter wheat is one of the most important grain crops in Sweden and is grown on an average of 350,000 of the country's approximately 1 million hectares of cereal crops. The average yield of winter wheat has not increased since 1990 and remains at approximately 6 tons per hectare (Figure 1.1). This development has occurred throughout Sweden, but the yield stagnation occurred later in Skåne County (Figure 1.2). In recent years, it would appear that crop yield in some areas is more varied and crop security has declined. It is possible to obtain high yields, but very low yields are more common today. One of the reasons is that high grain prices have resulted in the use of marginal soils, which have lower yield potential (SCB, pers. comm. 2012).

An international comparison shows that yield increases in winter wheat are lower in Sweden than in many other European countries, although a stagnation in yield increase for winter wheat has also been observed in other European countries (Figure 1.3).

There is growing competition for the world's arable land, which must not only feed a growing population, but must also be capable of producing bio-energy and industrial raw materials. This makes it increasingly important to find the causes behind the stagnation in winter wheat yield and the means to reverse it.

An increase in the average yield of winter wheat in Sweden of 20% over the next 10 years has been assessed by experts as being a reasonable target. The economic value of such an increase would be significant, e.g. with an average winter wheat price of SEK 1.50/kg, it would be equivalent to SEK 650 million.

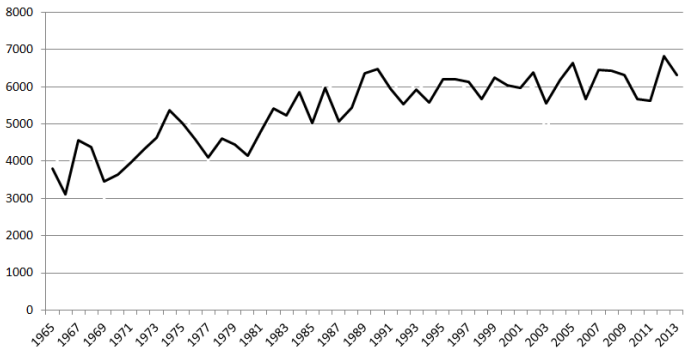

Figure 1.1. Winter wheat yield in Sweden, 1980-2013. The figure for 2013 is preliminary, but quite accurate (SCB 2013).

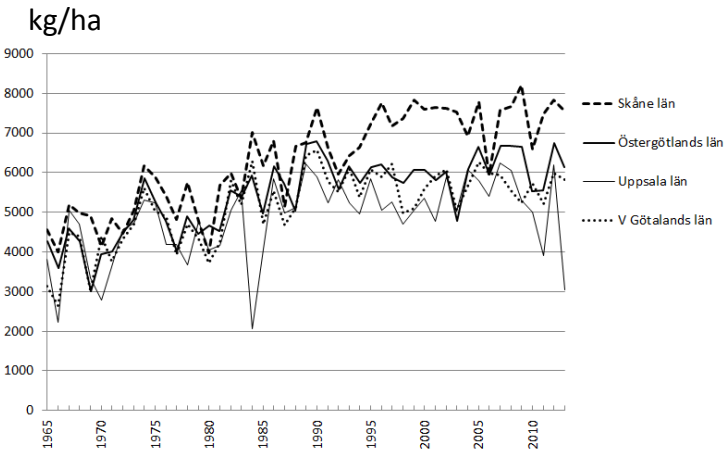

Figure 1.2. Winter wheat yield (kg/ha) in Skåne County, Östergötland County, Uppsala County, Västra Götaland County (data for Skaraborg County to 1984, for Västra Götaland thereafter), 1965-2013. The data for 2013 are preliminary, but quite accurate (SCB 2013).

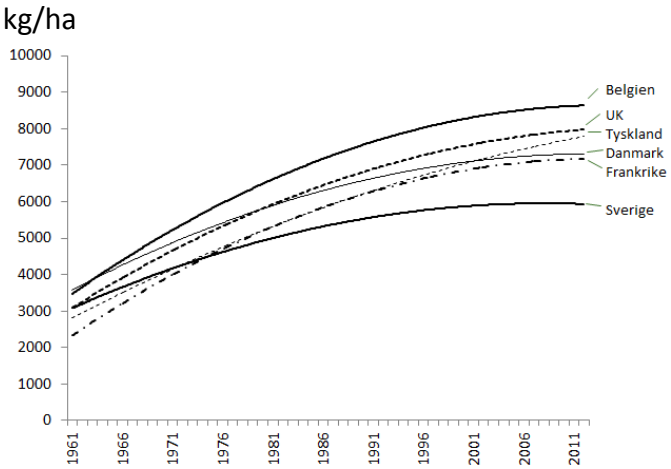

Figure 1.3. Winter wheat yield (kg/ha) in Belgium, the United Kingdom (UK), Germany, Denmark, France and Sweden, 1961-2012 (FAO 2012).

Project objectives

The primary objective of this project was to identify why winter wheat yield has stagnated in Sweden and to identify various ways to increase yield in future. The project included the following:

- Expert assessments, including literature reviews of relevant publications
- Summary of interviews with farmers describing management selections and farmers' own perceptions of why yields have stagnated
- Business intelligence - reporting of strategies selected to increase crop yields in other European countries
- A shortlist of high-priority research areas within which further study is needed. This includes new areas and a need for updated knowledge in existing areas.

The overall aim of the project was to identify knowledge gaps and potential causes for the stagnation in winter wheat yield and to prioritise the most fruitful initiatives to achieve the target of a 20% yield increase in 10 years. A significant restriction in the task was that this yield increase should not be achieved at the expense of farm profits or increased environmental impact. The results of the project are intended for use in designing new research and development projects to produce tools and guidelines that provide greater crop yields.

Hypothesis

The hypothesis tested in the interview survey of farmers was that "Some farmers are achieving higher yields because they have better management methods than others."

MATERIALS AND METHODS

The knowledge inventory was carried out in three areas; a review of existing literature, interviews with farmers and business intelligence analysis of similar international projects aiming to increase winter wheat yield. The project built upon frequent contacts between industry, farmers, advisors and researchers. This broad approach provided many perspectives on the analysis, while seminars and publications in the agricultural press led to the results receiving broad distribution.

Experience-based knowledge collected from farmers through in-depth interviews.
The interviews were conducted as paired studies, i.e. with farmers with average winter wheat yields and farmers with high winter wheat yields. This was in order to capture differences in management and cultivation between these groups of farmers in similar growing conditions. The interviews were conducted with farmers in the major winter wheat growing areas in Sweden: Skåne, Västergötland, Östergötland and Mälardalen. Within each area, four pairs of farmers were interviewed, giving a total of 32 farmers. A questionnaire was prepared to support the interviews. This questionnaire was designed so that it could be automatically compiled and processed. An independent expert was engaged to advise on the design of the interviews.

An expert assessment and knowledge inventory of existing literature was carried out by a group of experts/researchers from various fields. The work began by identifying the areas in

which the research team should compile and synthesise existing knowledge. The results obtained constitute later chapters of the proposed book. The researchers' task was to identify knowledge gaps and the need for new research and experiments. It was considered particularly important to proceed with these areas:

- Planting material
- Soil preparation and crop establishment
- Soil compaction
- Drainage and irrigation
- Fertilising and liming
- Crop rotation and preceding crops
- Weeds
- Pests
- Weather, climate and models

The work began with the development of common guidelines on how the literature should be reviewed and how the results should be presented. The assignment involved the researchers searching international and Swedish publications for relevant research results. They were also asked to assess the yield potential of the modified and improved cultivation strategies in their field. Each area was then compiled in a separate chapter of the combined report by a small group of approximately eight scientists, who worked intensely and in depth on this task. Moreover, approximately 15 additional researchers were involved to a lesser extent in the project. The research team held a number of meetings to discuss how the factors interact.

Business intelligence

Trip were made to England and Denmark. Strategies in France and Germany were studied through online research and contact with experts. In conjunction with the England trip, the English agricultural fair '*Cereals'* was also visited. In England, an advisory organisation has conducted a project on how to increase crop yields. Its approach is based on agricultural statistics, supplemented with data from interviews. The trip to England was fruitful and a discussion was begun on forming a common European network for the exchange of knowledge on increasing crop yields.

In Denmark, one of the key individuals working on the Danish winter wheat project was interviewed. That project ended some years ago. The visit was combined with participation in the Danish Cereal Network's annual conference in Copenhagen. Germany has similar strategic winter wheat projects aimed at increasing crop yields, while there is an especially strong focus on plant breeding in France. Denmark, however, has another task due to legislation. The main focus in Denmark has been to lower nitrogen rates and there is a statutory requirement to submit nitrogen accounts, which limits crop yields. This has resulted in new varieties being developed that have a high level of nitrogen use efficiency. Now Swedish farmers are also taking advantage of these varieties. In summary, there is currently no direct focus on increasing crop yields in Denmark at the moment.

RESULTS

The research studies and interviews identified the following potential methods for achieving crop yield increases and closing knowledge gaps:

POTENTIAL - PLANTING MATERIAL

- Leading researchers, gathered in a consortium, set the goal of increasing the yield potential by 50% in 20 years. The real rise in yield will decrease, because the greater the potential, the more difficult it is to provide the conditions for maximum yield.

KNOWLEDGE GAPS - PLANTING MATERIAL

- Improving light absorption and light conversion efficacy of varieties.
- Increasing the harvest index.
- Maintaining the yield potential through e.g. introduction of disease resistance in adapted varieties.
- Developing varieties adapted to different site conditions.
- Methods for the measurement and assessment of properties linked to light conversion efficacy.

POTENTIAL – CROP ESTABLISHMENT

- There are several potentially crop yield-enhancing factors linked to establishment. These are primarily related to sowing time, seed rate (perhaps primarily to reduce cost), seedbed composition and seed placement in the vertical and horizontal plane. Potential 0-10%.

KNOWLEDGE GAPS – CROP ESTABLISHMENT

- Extensive agronomic trials were conducted mainly back in the 1960s and 1970s. In many cases, new research on sowing time and seed rate is required as regards present-day varieties.
- There have been very comprehensive, detailed studies of seedbed function for spring-sown crops, but very few on autumn sowing. This applies, for example, to seedbed coarseness and the importance of drilling depth, which can have potentially major effects on crop establishment and yield. New research is needed in this area. Studies of e.g. row spacing would be of interest, as drills with increased row spacing have become more common today.

POTENTIAL - SOIL COMPACTION/LOOSENING

- Increased crop yield will be strongly dependent on the conditions at individual sites. The soil compaction/loosening effect can be expected to contribute an estimated yield increase of 0-15%

KNOWLEDGE GAPS - SOIL COMPACTION/LOOSENING

- The importance of subsoil conditions for yield potential is unknown. Studies are also needed on how to improve the long-term structure of the subsoil and facilitate crop root development.

POTENTIAL - DRAINAGE AND IRRIGATION

- Irrigation can increase yield by 20%. Supplemental irrigation at the right stage of development can increase yield by 15%. On soils with high groundwater, good drainage is essential for cultivation. If there are long periods of rainfall during the growing season, drainage has the potential to increase crop yield.

KNOWLEDGE GAPS - DRAINAGE AND IRRIGATION

- Irrigation research is needed to clarify drought tolerance and potential yield levels in newer winter wheat varieties.
- Practical and useful tools are required to determine irrigation scheduling.
- Supplemental irrigation has great potential, but the net effect may vary. Estimates are needed of what this can provide in Sweden under different conditions.
- Drainage trials are required to clarify the sensitivity to waterlogging of the newer winter wheat varieties.
- Optimal drain spacing and drain depth must be determined. Recommendations need to be updated for sustainable land usage.
- Recommendations for drainage coefficients must be updated, as changes in climate and land usage may result in increased runoff.

POTENTIAL - PLANT NUTRIENTS

- Only 10% (0.1 t/ha) of the lack of yield increase seen in SCB statistics, despite rising yields in field trials, can be explained by underestimation of the yield potential when deciding nitrogen fertilisation regime. An additional 13% can be explained by lower profitability in fertilising for higher yields after 2000 compared with prior to 2000.
- Trials show maximum crop yields that are 2-3 tonnes/hectare higher than the Swedish average yield according to SCB. There is thus great potential for yield increases. This potential is equally good in central Sweden and southern Sweden.
- Precision fertilisation, adapted to field variations, can increase yield by 3%.

KNOWLEDGE GAPS - PLANT NUTRIENTS

- In order to carry out site-specific fertilisation and calculate the correct optimal nitrogen requirements, better crop forecasting and predictions of soil mineralisation are needed. For this, practical techniques and fertilisation models must be developed, for example the use of zero and maximum test areas and hand-held fertiliser sensors.
- Phosphorus fertilisation of soils with low P values and liming on soils with low pH must to be encouraged to increase the potential for higher yield. The interaction between micro-nutrients and diseases must be investigated to eliminate the causes of yield stagnation.
- Fertilisation strategies with supplementary fertilisation linked to the actual development stage of the crop must be formulated for present-day varieties.
- Protein content can be viewed as a management tool, not just as a quality control parameter. Studies are needed on whether protein analyses can replace soil nitrogen analyses in detection of above/below optimal fertilisation.
- Interactive studies are needed on whether catch crops can be used as a safety net in relation to high fertiliser and high yields.

POTENTIAL - CROP ROTATION

- The potential to improve winter wheat yield by manipulating the crop rotation depends on how many hectares it takes to replace a poor preceding crop with a good one, and the ability to find space for grass crops in monotonous cereal rotations.

KNOWLEDGE GAPS - CROP ROTATION

- Satisfactory descriptions of the importance of crop rotation and cropping system.
- Tools for managing complex systems.
- Short- and long-term effects of crop rotation on weeds and pests and their interaction

with the environment.

POTENTIAL - WEEDS

- High minimum level! The greatest potential for higher yields is to be found in cases where weed control is currently not optimal.

KNOWLEDGE GAPS - WEEDS

- Increased knowledge is needed regarding the competitive impact of individual weed species. There is insufficient data to analyse the effect of e.g. blackgrass and barren brome.
- A more thorough study of the variations in previous field trials could provide valuable information on the factors influencing treatment effect.
- Effective, integrated strategies must be developed, to manage increasingly resistant grass weeds in particular.

POTENTIAL - PESTS

- The yield potential in pest-free conditions is unknown. The farmer's goal is generally financial yield rather than maximum yield.

KNOWLEDGE GAPS - PESTS

- Interactions among harmful organisms and between harmful organisms and other factors in the crop stand.
- Explanatory relationships between attacks by individual harmful organisms and combinations of several harmful organisms and yield.
- How populations of harmful organisms change over time and the consequences of these changes for the crop.
- Ability to manage new harmful organisms, altered harmful organisms, the effects of climate change, pesticide resistance and cessation of statutory pesticide use recording.
- Short- and long-term effects of cultivation practices and other preventive measures.
- Need for the resistance breeding work, focusing on Nordic conditions.

POTENTIAL - WEATHER, CLIMATE AND MODELS

- Difficult to predict. In a growth model, winter wheat of a given variety grown in Uppsala, with a 1.7°C increase in temperature, a 7% increase in precipitation and a 45% increase in carbon dioxide levels, was calculated to increase its aboveground biomass by 15%. In similar European scenarios, however, the grain yield did not increase, but rather decreased due to a shortened kernel filling period.

KNOWLEDGE GAPS - WEATHER, CLIMATE AND MODELS

- The importance of frost, fungus and ice burn for winter kill and canopy cover in spring should be investigated, as well as the link between spring cover and yield.
- The effects of extreme weather events on local production and crop production security in relation to cultivation and growing conditions should be determined.
- Germination models based on eco-physiological processes which can explain the role of weather, climate and variety characteristics on variations in observed yields should be developed and tested.
- The ability of eco-physiology-based germination models to predict winter wheat yields in practical farming in Sweden should be compared with the predictability of agro-climatic indices based on eco-physiological processes.

POTENTIAL - MANAGEMENT

- 10-20%, maybe even more.

KNOWLEDGE GAPS - MANAGEMENT

- One conclusion is that there is a great need to clarify what can be gained from good management.
- There is a need for clear examples of what late sowing, poor drainage, etc. cost in terms of lost revenue.
- The importance of precision liming and precision fertilisation needs to be better highlighted.

DISCUSSION

Combining practical experience with scientific expertise and a review of previous trial material proved valuable. It resulted in a list of knowledge gaps which need to be filled. Likewise, gaining an international insight into the strategies which other countries use to increase crop yields was successful. It showed that countries have very different strategies for increasing crop yields. None of the other four countries studied here had a joint industry response to the winter wheat issue as such. There is thus great potential to increase crop yield through more collaboration and knowledge exchange between countries that have similar growing conditions in terms of winter wheat.

This project involved both quantitative and qualitative research and this resulted in different approaches to how the data were processed. Data from the interviews with farmers were used to identify differences between the average and high-achieving groups, but sometimes the results showed a tendency rather than a significant value. The interviews with farmers also showed which questions farmers could easily answer or not, i.e. the parameters that are known and unknown to them. This is valuable information in the task of identifying the parameters that are central to achieving a yield increase on national level. Methodological experiences from the interview study are other valuable results which can be used in new research projects or to design advisory tools.

The great focus on the winter wheat crop will probably result in higher yields. How to increase winter wheat yield has now become a widely discussed issue in many parts of the rural community. It has also become a topic raised at a number of seminars throughout the country. The reporting of some project results by the media during the process has created a desire for more results. It was also a great advantage that the project involved representative farmers, advisors, researchers and experts. The involvement of this entire stakeholder chain from the outset assures the quality of the results and the likelihood that the benefits from the results will increase.

PUBLICATIONS

* The Winter Wheat book, with a summary of the results (170 pages).
* Summary script issued with the *Theme Day for Balanced Cultivation*, January 2012.
* Article in *Lantmannen* on the project and some results.
* Article in *Grodden* on the project and some results.

* Article in V*äxtpressen* on the project and some results.
* Article in the journal *HS Kalmar*.
* Appendix in *Agricultural Business.*
* Summary for the Växjö Meeting.
* Two articles for *Lantmannen* magazine.
* A number of news items in other agricultural magazines.
* A summary brochure for Borgeby and Brunnby field fairs 2014.

CONCLUSIONS - Current benefits with advice for the industry

Significance for the industry

It is too early to measure any increases in crop yield, but the major focus on winter wheat has directed attention to improving production of this crop, which will most likely lead to higher yield. Previous projects involving sugar beet and oilseed crop cultivation have helped achieve recent crop yield increases and this is also likely to be the case for winter wheat. The researchers' knowledge, summarised in different areas, provides a good picture of the scope of present knowledge. This will facilitate future decisions on new research areas that should be prioritised. The interviews with practical farmers clearly demonstrated the importance of good management. The project has shown that yields can be increased by having good soil fertility and due to good management. This is an example of how sustainable intensification can be achieved.

Goal achievement

This project comprised a unique collaboration between farmers, advisors, researchers and industry, all of whom participated and helped design the project. They met in different configurations at work meetings, workshops and seminars on numerous occasions. This broad support made it possible to highlight issues from many different angles. Many creative and interesting meetings were held during the project. *Odling I Balans (Farming in Balance, www.odlingibalans.com)* has a large network and is a neutral party, which was a prerequisite for successful cross-sector cooperation. For example, there were new interactions between different departments at SLU and new collaborations were initiated between the two advisory organisations. Several of these new configurations then got together and planned new joint funding applications for research on the winter wheat issue.

Early involvement of many in the industry was a successful approach, as it led to a natural interest in the results. This means the results will be implemented and gain acceptance more quickly. The results pointed out the need for innovation, especially in management. This is now a subject of considerable debate, thanks to this project. A number of new issues needing further research have also been identified. There has been huge media interest in the project and "there is probably no grower in Sweden who has not heard of the project."

DISSEMINATING THE RESULTS TO THE INDUSTRY

The results from the project will be presented at a number of workshops and seminars. One meeting was specifically directed at researchers before the funding application period, i.e. in

August 2014. There have also been two major theme days in the *Odling I Balans*, programme, which were about achieving new heights for winter wheat. Both theme days were well attended, with approx. 100 people at each event. The Swedish Economic and Rural Societies have built on the results from this study at their own conferences and meetings with farmers.

* *Odling I Balans* theme day, January 2013, approx. 100 participants.
* *Odling I Balans*, theme day, January 2014, approx. 120 participants.
* *Växjö* Meeting, December 2012.
* Meeting in Skaraborg, January 2012.
* LRF growth group, *(LRF tillväxtgrupp)* two events 2013-2014.
*Seven *Växtråd* post-season meetings in late November/December, with a total of 150-200 participants.
* Partnership Alnarp held a meeting in Kalmar at the end of November 2013, at which a number of issues were raised.
* The *SVEA Conference*, January 2014, Brunnby.
* *SPMO* (Seed and Oilseed Growers in Mälardalen), annual meeting.
* Soil tillage, *(Jordbearbetningsdag)* March 2013 and 2014.
* *Ämneskommiteerna jordbearbetning*, Subject committee meeting on soil tillage, in 2014.
* A number of final presentations are scheduled for during the autumn 2014.