A Farmer's Toolbox for Integrated Pest Management

AGRI/2020/OP/0003

Case study "A large-scale pesticide-free wheat production program in Switzerland"

A large-scale pesticide-free wheat production program in Switzerland

Abstract

The Swiss producer organisation IP-SUISSE introduced a pilot program for non-organic pesticide-free wheat production in 2018/19, which then opened to all producers in 2019/20. The program aims to reach a large-scale adoption of 20-50% of Swiss wheat production - and is the first of its kind in Europe. Farmers in the program substitute pesticides in wheat production with a range of integrated pest management practices. They are compensated with a price premium and a federal direct payment. The program builds on a long-standing extensive wheat production program of IP-SUISSE which has a market share of around 50% of Swiss wheat production. This case study describes the history and development of this extensive and pesticide-free production program. Following, the case study investigates adoption barriers and hurdles for farmers adoption, effects of the program on pesticide reduction, farmers' incomes, and consequences for the development of sustainable wheat production practices and technologies in Switzerland. Finally, the potential for pesticide use reduction through non-organic pesticide-free production programs for other crops and countries is discussed.

1. Introduction

The producer organisation IP-SUISSE is currently establishing a large-scale pesticide-free but non-organic, wheat production program in Switzerland. The program is building on a long-standing extensive wheat production program of IP-SUISSE ("Extenso" production), which covers ~50% of Swiss wheat production and exists since 30 years.

Producers in this new program are prohibited from using synthetic pesticides in wheat production but they are not restricted in their use of other inputs or pesticide use in the rest of the crop rotation. They substitute pesticide use by a range of integrated pest management practices and receive a market compensation (price add-on) and a federal direct payment for pesticide-free production. The pesticide-free production program started with a pilot program of 1200 ha in the growing season 2018/19 and was opened for participation to all producers from the growing season 2019/2020 onwards. IP-SUISSE reported that the program was adopted on around 4 000 hectares already in the first season, and a recent survey found that 58% of all producers were willing to adopt the program.[1,2] Despite a higher expected profitability of wheat production in the program, significant adoption barriers, such as the availability of machinery and knowledge on pesticide substitution, higher economic risks and farmers' perception of the program's economic and environmental effects exist.[3,4]

In this context, the major Swiss retailer Migros has further announced to only sell bread from "pesticide-free" wheat from 2023 onwards, strongly supporting the program. To meet this demand, the pesticide-free wheat production program is therefore aiming to reach a market share of at least 20% of Swiss wheat production in the next years. The program thus has major implications for pesticide use reduction in Switzerland and is the first large-scale pesticide-free but non-organic production program in Europe.

Pesticide-free production programs have the potential to reduce pesticide use of farmers on a large-scale, while posing significantly lower adoption barriers and hurdles than production systems such as organic farming, which impose stricter restrictions on farmers' input use on a farm-level. The novel pesticide-free production scheme in Switzerland therefore has a high relevance for the *Pilot project – Developing a farmers' toolbox for integrated pest management practices from across the Union*, as it may serve as an example for the introduction of similar production programs in other crops and countries in Europe. The long-standing development and establishment of extensive wheat production in the IP-SUISSE production programs further provides the unique opportunity to study uptake decisions, adoption barriers and economic and environmental effects of pesticide-free production practices in a European context. Finally, the case study allows to investigate the importance of farmers' experiences with integrated production practices and the development of new practices and technologies for pesticide-use reduction (in wheat production).

[1] BauernZeitung (2021). "Trotz der Nässe ist der herbizidfrei angebaute Weizen sauber geblieben", published 24.06.2021 in BauernZeitung, Bern, Switzerland.
[2] Möhring, N. & Finger, R. (2021). Pesticide-free but not organic: the adoption of a large-scale wheat production program in Switzerland. Food Policy (*under review*).
[3] Böcker, T., Möhring, N., & Finger, R. (2019). Herbicide free agriculture? A bio-economic modelling application to Swiss wheat production. *Agricultural Systems*, *173*, 378-392.
[4] Möhring, N. & Finger, R. (2021). Pesticide-free but not organic: the adoption of a large-scale wheat production program in Switzerland. Food Policy (*under review*).

2. Research theme

This case study will explore the development of a unique large-scale pesticide-free but non-organic wheat production program in Switzerland and its potential for reducing the dependency on pesticide use, also in other crops and countries. To explore long-term drivers and effects it will further extend the analysis of the case study to include the long-standing extensive wheat production program (existing for 30 years) on which the pesticide-free wheat program is based.

More specifically, the case study will first introduce the history and structure of the program, as well as the involved stakeholders and their role in establishing the program. Second, it will discuss potential effects of the program on reducing farmers' dependency on pesticides and explore effects of the program on the development and establishment of practices and technologies supporting farmers in pesticide-free and -reduced production. Further, it will discuss economic effects of the program and potential trade-offs with other goals of agriculture. Third, the case study will describe and discuss potential adoption determinants and barriers for farmers in the uptake of pesticide-free wheat production. Finally, the case study will explore the potential of the Swiss pesticide-free production program for pesticide reduction in other crops and countries.

3. Methodology

The case study was conducted through an extensive literature review, including especially the results of the HerbiFree and PestiFreeWheat research projects, which were conducted between 2018-19 and 2019-20 at the Agricultural Economics and Policy Group at ETH Zurich[5]. More specifically, these projects were built on results of an ex-ante simulation of the environmental and economic effects of the new production program with a bio-economic model, a large-scale survey with producers on program adoption, an econometric analysis of farmers' adoption determinants and barriers, as well as interviews and repeated exchanges with all relevant stakeholders (IP-SUISSE, Migros, Swiss wheat producers and advisory service experts from Agroscope and HAFL). Results and data of the research projects are publicly available, e.g. in the ETH research collection.

Since the pesticide-free wheat production program has just recently been introduced, long-term effects on prices, adoption and pesticide use reduction in conventional, pesticide-free, Extenso and organic wheat in Switzerland, cannot be assessed yet. The effects of the Extenso wheat production program in Switzerland, which has been in place for 30 years, and on which the pesticide-free program builds, will be considered instead.

4. Activities and results

In this section, the history, structure (including relevant stakeholders) and objectives of the Extenso and pesticide-free wheat production program will be presented. This will be followed by short- and long-term impacts of the program on the reduction of pesticide dependency, farmers' incomes, potential trade-offs with other environmental goals and the development and implementation of practices and technologies for farmers' pesticide substitution. Finally,

[5] https://aecp.ethz.ch/research/Herbifree.html and https://aecp.ethz.ch/research/PestiFreeWheat.html

literature on the determinants and barriers for farmers' adoption of the program will be summarised.

4.1 History, structure and objectives of the program

Pesticide-free wheat production

The pesticide-free wheat production program was established by the producer organization IP-SUISSE[6] with the objective of reducing the dependency on pesticides in Swiss wheat production on a large scale. The program started in 2018/19 as a pilot on around 1200 ha and was marketed through a Swiss bakery (Fredy's AG). Since the growing season 2019/2020 the pesticide-free wheat production program was opened to all producers and IP-SUISSE has announced that pesticide-free wheat was produced on around 4 000 ha in the first growing season open to participation for all producers. In 2020, the major Swiss retailer Migros (processing around 20% of Swiss bread wheat production) further announced to only sell bread from "pesticide-free wheat" from 2023 onwards,[7] further pushing the program. To estimate potential economic and environmental effects of the program and to identify potential adoption determinants and barriers, two research projects were conducted at ETH Zürich (HerbiFree and PestiFreeWheat).

Producers in the program are prohibited from using chemical-synthetic pesticides during wheat production. However, contrary to organic farming, their use of other inputs in wheat production, i.e. fertilizers, is not restricted and pesticides can still be applied in other parts of the crop rotation. IP-SUISSE producers further have to comply with some general requirements, like enhancing biodiversity and restrictions to the crop rotation (e.g. no wheat-wheat rotations and maize-wheat rotations under obligations) (IP-SUISSE, 2021). Producers participating in the program receive a market compensation (a price premium of currently 15 CHF/dt) and a direct payment from the Swiss federal government (400 + 250 CHF/ha).[8]

Extenso wheat production

The pesticide-free wheat production program is building on the Extenso program, an extensive wheat production program that was established by IP-SUISSE almost 30 years ago. Producers in the program are prohibited to use fungicides, insecticides and growth regulators but can still use seed coatings and herbicides in wheat production (IP-SUISSE, 2021). Extenso wheat producers receive a price add-on (currently around 5 CHF/ ha) additional to a federal direct payment (400 CHF/ha).[9] Extenso production currently accounts for around 50% of the Swiss wheat production surface (120 000 ha, IP-SUISSE, 2021) and adoption rates are relatively stable since around 1997.[10] Swiss wheat producers can therefore choose between conventional, Extenso, pesticide-free and

[6] IP-SUISSE is a Swiss producer organisation for integrated production, controlling and marketing IP-SUISSE products and the IP-SUISSE labels. Several marketing channels for IP-SUISSE products exist from direct marketing to a long-standing collaboration (20 years) with the major Swiss retailer Migros. 18500 out of the 50000 Swiss farms are currently IP-SUISSE members (IP-SUISSE 2021, BLW 2020).

[7] Migros (2020). "Migros setzt bei Brot aus der JOWA-Bäckerei auf komplett pestizidfrei angebauten Weizen", retrieved from https://www.migros.ch/de/unternehmen/medien/mitteilungen/show/news/medienmitteilungen/2020/pestizidfreier-weizenanbau.html (last accessed July 12th, 2021).

[8] Möhring, N. & Finger, R. (2021). Pesticide-free but not organic: the adoption of a large-scale wheat production program in Switzerland. Food Policy (under review).

[9] AGRIDEA. (2019). AGRIDEA Preiskatalog. AGRIDEA, Lindau, Switzerland.

[10] Finger, R. (2010). Evidence of slowing yield growth–the example of Swiss cereal yields. *Food Policy*, *35*(2), 175-182.

organic wheat production. See the table below for an overview of the different wheat production systems.

4.3 Environmental and economic impacts of the program

Reducing the dependency on pesticide use

Pesticide use in the Extenso and pesticide-free wheat production is on average reduced by 1.5 standard dosages and 2.5 standard dosages of pesticide use per hectare compared to conventional wheat production in Switzerland.[11,12] Intensive margin effects (i.e. reduction in per hectare use of pesticides) of the program are therefore small compared to potential effects in crops like potatoes, which on average have a five to six times higher pesticide use per hectare. However, like in the European Union, winter wheat is the most important crop in Switzerland and cultivated on around 250 000 ha.[13] The large-scale adoption of Extenso wheat production on currently 120 000 ha therefore leads on average to a potential yearly reduction of 180 000 dosages of pesticides, compared to conventional wheat production. Similarly, the pesticide-free wheat production program has led to a potential reduction of 10 000 standard dosages of pesticides in its first year, compared to conventional wheat. If all Extenso producers would take up pesticide-free production, this would lead to a potential reduction of 300 000 standard dosages of pesticides compared to conventional and 120 000 standard dosages of pesticides compared to Extenso production each year[14].

Properties of Swiss wheat production systems

	Conventional	Extenso	Pesticide-free	Organic
Yields	70 dt/ha	55 dt/ha	(52 dt/ha)*	44 dt/ha
Prices	50 CHF/dt	50 CHF/dt + 5 CHF/dt premium	50 CHF/dt + 15 CHF/dt price premium*	106 CHF/ha
Direct payments	-	400 CHF/ha	650 CHF/ha	1600 CHF/ha

[11] de Baan, L., Spycher, S., & Daniel, O. (2015). Einsatz von Pflanzenschutzmitteln in der Schweiz von 2009 bis 2012. Agrarforschung Schweiz, 6(2), 48-55.
[12] Finger, R., Böcker, T., Möhring, N., & Dalhaus, T. (2016). Ökonomische Analyse des Einsatzes von Pflanzenschutzmitteln – Risikoaspekte und Lenkungsabgaben. Bericht zu Händen des Bundesamts für Landwirtschaft. ETH Zürich and University Bonn, October 2016.
[13] Bundesamt für Landwirtschaft (BLW) (2020). Agrarbericht 2020, Bern, Switzerland.
[14]This is a simple prognosis based on average pesticide use and extent of the respective production systems and does not account for potential adjustments of farmers, e.g. in other parts of the crop rotation. Möhring and Finger (2021) report that only 20% of farmers were planning to increase pesticide use in other parts of the crop rotation after the adoption of pesticide-free wheat production.

Production obligations	Proof of ecological performance	Proof of ecological performance IP-SUISSE compliance criteria Prohibits use of growth regulators, fungicides, insecticides.	Proof of ecological performance) IP-SUISSE compliance criteria Prohibits use of all chemical-synthetic pesticides	Prohibiting synthetic pesticides and fertilizer use on a farm-level

Yields, prices, and price premia for the year 2019/2020 according to AGRIDEA (2019). Yields for pesticide-free wheat are based on predictions from Böcker et al. (2019). Swiss farmers receiving direct payments are obliged to follow a "proof of ecological performance". Table adapted from Möhring and Finger (2021).

Practices and technologies for pesticide reduction

The introduction of the Extenso and pesticide-free program further had (will have) effects on the acceptance, reliability and distribution of substitutes for pesticides amongst Swiss farmers. It further affects the development of new measures and technologies, as well as infrastructure for knowledge transmission, processing and marketing of the wheat. Substitution of pesticide use in Extenso and pesticide-free production is realized through a range of agronomic measures that closely follow the principles of integrated pest management. Those include the choice of suitable crop rotations, resistant varieties, and mechanical wheat control measures amongst others.[15]

Although the management measures and technologies for the substitution of pesticides have partly long been established and are for example often used in organic farming, they are often less familiar to conventional farmers. The long-term establishment of the Extenso program has therefore led to the development of farmers' and advisory services' knowledge on the application of substitutes for pesticide use, i.e. increasing confidence of farmers in those measures and reducing their dependence on pesticides. For example, specialized field trials are conducted each year, and courses, literature and data on Extenso production are available to farmers in all parts of Switzerland. The long-term continuation of the program has further supported an emphasis on breeding of wheat varieties suitable for Extenso production. Notably, they have a high resistance to plant diseases, while maintaining baking quality and are also exported to other countries.[16,17] The large-scale establishment of the program has further led to adjustments of all actors along the food value chain, starting from the production and provision of seeds, the establishment of separate infrastructures for measuring, transportation and milling of Extenso wheat, to the establishment of new marketing channels for products from Extenso wheat. Similarly, such infrastructure is currently being developed for pesticide-free production.

[15] Möhring, N. & Finger, R. (2021). Pesticide-free but not organic: the adoption of a large-scale wheat production program in Switzerland. Food Policy (*under review*).
[16] Fossati, D. & Brabant, C. (2003). Die Weizenzüchtung in der Schweiz. *AgrarForschung*, 10 (11-12), 447-458.
[17] Stamp, P., Fossati, D., Mascher, F. & Hund, A. (2014). Wie geht es weiter mit der Weizenzüchtung? *Agrarforschung Schweiz* 5 (7-8), 286-291.

Farmers, IP-SUISSE employees and other actors of the food-value chain have in discussions repeatedly emphasized the importance of a long-standing and reliable cooperation between the different partners guaranteeing trust in the stability of the new program and the long-term rentability of investments in infrastructure and knowledge.

Economic effects of the program

Extenso wheat has been found to have a 20% lower average yield compared to conventional production.[18] Additionally, it has been found that Extenso yields have been growing more slowly over time than conventional wheat yields, which might be due to a focus on more robust and resistant varieties.[19] Under pesticide-free production, additional yield losses of on average 6% are expected compared to Extenso production.[20] The small, expected yield gap between Extenso and pesticide-free wheat is due to the high efficiency of substitutes for herbicide use in wheat production, mainly mechanical weed control measures. However, differences in yields between the different production systems might be heterogenous between farmers and are highly dependent on growing conditions, such as topography, soil and environmental conditions. Average yields of Extenso and pesticide-free production are around 20% higher than organic production, emphasizing the importance of restrictions on fertilizer use and whole farm-level restrictions of pesticides for yields (see Table 1 for an overview).

Further, El-Benni and Finger[21] find that farmers on average almost compensate for lower yields in Extenso production through higher prices and lower costs for inputs. Including federal direct payments, they find a higher average profitability of Extenso production. Moreover, they find that the Extenso program has been successful in guaranteeing participating producers more stable prices than conventional wheat producers (El-Benni and Finger, 2013), while yield risks were higher than in conventional production. In line with these findings, Böcker et al. [22] expect that participation in pesticide-free production will on average increase profitability of wheat production for farmers. However, they also emphasize that a high variability across farmers and growing conditions exists, which might render a transition from Extenso to pesticide-free production more difficult for some farmers.

Since the pesticide-free program has only recently been established, it is not possible yet to foresee its mid- and long-term effects on markets for conventional, Extenso and organic wheat. If the pesticide-free program remains economically attractive, also more conventional farmers, who were not previously Extenso producers, might adopt pesticide-free adoption. Similarly organic production with its higher direct payments and prices might become more appealing to pesticide-free producers once they are familiar with production and risk management tools in pesticide-free production.

[18] AGRIDEA. (2019). AGRIDEA Preiskatalog. AGRIDEA, Lindau, Switzerland.
[19] Finger, R. (2010). Evidence of slowing yield growth–the example of Swiss cereal yields. *Food Policy*, *35*(2), 175-182.
[20] Böcker, T., Möhring, N., & Finger, R. (2019). Herbicide free agriculture? A bio-economic modelling application to Swiss wheat production. *Agricultural Systems*, *173*, 378-392.
[21] El Benni, N., & Finger, R. (2014). Where is the risk? Price, yield and cost risk in Swiss crop production. *Review of Agricultural and Environmental Studies-Revue d'Etudes en Agriculture et Environnement (RAEStud)*, *95*(906-2016-71350), 299-326.
[22] Böcker, T., Möhring, N., & Finger, R. (2019). Herbicide free agriculture? A bio-economic modelling application to Swiss wheat production. *Agricultural Systems*, *173*, 378-392.

Trade-offs in Extenso and pesticide-free production

The introduction of Extenso and pesticide-free wheat bears trade-offs between pesticide reduction, yield levels and risks (see above). Additionally, quality issues might arise: high pest pressure might lead to high levels of mycotoxins and downgrading of wheat if diseases cannot be managed in Extenso and pesticide-free production. Further, the substitution of herbicides with mechanical wheat control can lead to a higher fuel consumption (and thus greenhouse gas emissions of agriculture). It also might lead to lower levels of soil conservation practices and associated benefits if alternatives for tillage, such as harrow combing (with lower weed control efficiency) are not established.[23,24]

4.2. Determinants and barriers for farmers' adoption

Understanding farmers' decisions is central for the establishment of new production schemes on a large scale. The below sections will therefore summarize findings on the adoption determinants and barriers for Extenso and pesticide-free wheat production.

Finger and El-Benni[25] conduct an empirical analysis on the adoption of Extenso wheat production between 1992-2000 (i.e. since the start of the program) using bookkeeping data. They find that adoption of the Extenso program in its early phase was especially driven by smaller farm sizes, lower yield levels and low input use, indicating some free-riding effects in program adoption. They further note that while in a later phase also larger farms adopted the program, they still had comparably lower yields and input use. Finally, they find that wheat prices and the magnitude of direct payments for Extenso production were critical for program adoption, underlining the importance of economic drivers for program adoption (i.e. compensating lower yield levels). They conclude that differentiated payments, adopted to the opportunity costs of farmers would be more effective and efficient for program design.

Möhring and Finger[26] conduct a large-scale survey with all IP-SUISSE wheat producers in 2020 (4749, 1105 complete responses) and analysed adoption determinants and barriers for pesticide-free wheat production.[27] They find that 58% of Extenso farmers have already adopted or are willing to adopt pesticide-free wheat production. In contrast to Finger and El-Benni (2013), Möhring and Finger (2021) find that structural characteristics, such as farm size, environmental conditions (i.e. climate, pest pressure and soil conditions), topography and yield levels do not drive farmers' adoption decisions for pesticide-free production. They identify three major areas of adoption determinants: i) farmers expectations on environmental effects of the program, ii) their expectations on production levels and risks of the new program and iii) the availability of knowledge and machinery for the substitution of herbicides. They conclude that the large-scale adoption of the program requires i) information on the environmental effects of the program, i.e. environmental benefits of reduced pesticide use, ii)

[23] Böcker, T., Möhring, N., & Finger, R. (2019). Herbicide free agriculture? A bio-economic modelling application to Swiss wheat production. *Agricultural Systems*, *173*, 378-392.

[24] Böcker, T., Britz, W., Möhring, N., & Finger, R. (2020). An economic and environmental assessment of a glyphosate ban for the example of maize production. *European Review of Agricultural Economics*, *47*(2), 371-402.

[25] Finger, R., & El Benni, N. (2013). Farmers' adoption of extensive wheat production–Determinants and implications. Land Use Policy, 30(1), 206-213.

[26] Möhring, N. & Finger, R. (2021). Pesticide-free but not organic: the adoption of a large-scale wheat production program in Switzerland. Food Policy (*under review*).

[27] The dataset is publicly available: Möhring, N. & Finger, R. (2020). Adoption of pesticide-free wheat production in Switzerland (dataset). https://doi.org/10.3929/ethz-b-000450297

field trials and analyses of economic data to support farmers in their adoption decisions and iii) support for farmers substitution of pesticides. The latter may include specialized advisory services and courses for farmers, support for investments and availability of machinery (e.g. through machinery rings or contractors). Wang et al. further highlight that the establishment of knowledge on such new and innovative systems in the neighbourhood and its transmission through neighbours can be crucial for adoption. They highlight the importance of reaching a critical mass of farmers, who can pass on knowledge to reduce adoption costs and risks. Möhring and Finger (2021) further discuss the potential trade-offs for farmers, who are already participating in soil conservation schemes. Soil conservation and pesticide-free production at the same time is possible, i.e. through the use of harrow combing, but may come with a higher uncertainty and lower efficiency than the use of deep tillage, e.g. ploughing.

5. Discussion and conclusions

This case study has presented a pesticide-free wheat production program that was established by the producer organization IP-SUISSE in Switzerland in 2018/19. IP-SUISSE aims to achieve a large-scale adoption of the program among Swiss wheat producers. The program has been taken up by farmers on around 4 000 ha in its first year and is supported by the major Swiss retailer Migros, who wants to sell only bread from "pesticide-free wheat" by 2023 (requiring that around 20% of Swiss wheat must be produced pesticide-free by then).

A large-scale adoption of the program would significantly reduce pesticide dependency of Swiss agriculture in the short-term. In the mid- to long-run it might further help to increase knowledge and confidence of farmers in regard to substitutes for pesticides, as well as investments in infrastructure (i.e. advisory services) and machinery. Practices such as the adoption of crop rotations and cropping practices, and the use of mechanical pest control are generally known (i.e. are central in the framework of integrated pest management) but are not taken up by a lot of conventional farmers yet. They often require more investments in machinery and knowledge and may bear economic losses and higher risks (Möhring et al., 2020). Furthermore, a long-run and large-scale pesticide-free wheat production program might accelerate and enable the development of technologies and breeding of resistant varieties, as observed for the Extenso wheat production program in Switzerland.

A central component of the program is its financial support, both by a market-based payment for pesticide-free wheat and a federal direct payment supporting potential transition costs and higher risks in the program and thus incentivising a large-scale take-up. The support of actors along the whole food-value chain, from the supply of suitable seeds and farmers changing production practices, to the creation of separate logistics and marketing channels, was further key for the development of the program. This was, amongst others, enabled by the long-standing experience and relation of IP-SUISSE with other food-value chain actors. IP-SUISSE has been supporting and marketing extensive production programs (Extenso) for the last 30 years, and Extenso wheat has a market share of around 50% in Swiss wheat production.

Studies expect that farmers will overall gain economically from adopting the program, but still important adoption barriers exist. Especially farmers heterogenous perceptions of the program's negative effects on yields and risks seem to be an important adoption barrier.

Further the availability of substitutes for pesticides, i.e. mechanical weed control plays an important role. Additional to lower food production levels, important trade-offs of the program are related to the higher use of mechanical weed control measures. They include a higher fuel consumption and emissions and a potentially lower level of soil conservation techniques of farmers participating in the program.

Take-home messages

The main take-home messages from the case study are:

1) The establishment of a large-scale non-organic program for pesticide-free wheat production (in Switzerland) is possible.
2) The program significantly reduces the dependency of Swiss farmers on pesticides in wheat production, a major European crop.
3) Additional to its immediate effects on pesticide use, the program is expected to support the development and establishment of knowledge, infrastructure, and technologies for pesticide reduction.
4) Key for the establishment of the program was the contribution of actors along the whole food-value chain, including input suppliers, farmers, food processers and retailers.
5) The program compensates lower yields, higher risks and investments of farmers in machinery and knowledge with a market compensation and federal direct payments.
6) Major adoption barriers for farmers are expectations on negative economic effects and the availability of machinery and knowledge for mechanical weed control.
7) Potential trade-offs exist with regard to lower food production, higher fuel consumption and emissions and lower levels of soil conservation.

Outlook

Long-term effects of the introduction of the pesticide-free wheat production program on markets for conventional, Extenso and organic wheat production in Switzerland are unclear yet. The introduction of the new program could lead to a lower share of conventional wheat and a higher share of organic production in Switzerland, as producers become more familiar with substitutes for pesticides and the management of associated risks. Experiences from the introduction of the Extenso wheat production scheme show that the stability of market compensations and direct payments in comparison with the conventional wheat price will be key for the uptake by conventional farmers. Studies show that results on the stability of yields under pesticide-free production and the availability of training and machinery could be key for the uptake of current Extenso producers. IP-SUISSE has further announced to extend extensive production schemes to other sectors, such as wine production (Denner, 2021).

Relevance for other crops and countries

The case study shows that establishing pesticide-free crop production systems, in-between conventional and organic farming systems, could be an important pathway for a large-scale reduction of farmers' dependency on pesticide use. Pesticide-free production systems of single crops are less restrictive than organic farming, which imposes farm-level restrictions. They are therefore more flexible to farmers and have a higher adoption potential. The question arises if such production programs could also successfully be established in other countries or for other crops.

The findings of the case study underline that in order to establish such programs on a large-scale, contributions from all actors along the whole food-value chain and farmers' trust in the program's stability, i.e. through a long-time partner, are required. Further, the creation of a label, creating a market compensation for farmers' compensation, additional to direct payments seems to be key for the creation of a successful and durable program.

If these conditions are met, the establishment of similar production programs for other countries seems to be a feasible pathway for a large-scale reduction of farmers dependency on pesticide use. However, suitability and adoption of such programs might be highly dependent on local growing and market conditions, such as climate, pest pressure, market organization and consumers' willingness to pay in the respective countries.

The current development in Switzerland further shows that such programs could also be extended to other crops. The expansion of such programs to other crops is also highly dependent on the availability of effective and efficient alternatives for pesticide use at reasonable costs. The case study shows that the large-scale establishment of such systems can support and accelerate the development and broad diffusion of new practices and technologies to reduce pesticide use in the agricultural sector.

Annex I - Bibliography

AGRIDEA. (2019). AGRIDEA Preiskatalog. AGRIDEA, Lindau, Switzerland.

BauernZeitung (2021). "Trotz der Nässe ist der herbizidfrei angebaute Weizen sauber geblieben", published 24.06.2021 in BauernZeitung, Bern, Switzerland.

Bundesamt für Landwirtschaft (BLW) (2020). Agrarbericht 2020, Bern, Switzerland.

Böcker, T., Möhring, N., & Finger, R. (2019). Herbicide free agriculture? A bio-economic modelling application to Swiss wheat production. *Agricultural Systems*, *173*, 378-392.

Böcker, T., Britz, W., Möhring, N., & Finger, R. (2020). An economic and environmental assessment of a glyphosate ban for the example of maize production. *European Review of Agricultural Economics*, *47*(2), 371-402.

de Baan, L., Spycher, S., & Daniel, O. (2015). Einsatz von Pflanzenschutzmitteln in der Schweiz von 2009 bis 2012. Agrarforschung Schweiz, 6(2), 48-55.

Denner (2021). "Denner und IP-SUISSE lancieren ein Projekt zu verantwortungsvollem Handeln", retrieved from https://www.denner.ch/de/ueber-uns/nachhaltigkeit/nachhaltig-leben/ (last accessed July 14th, 2021).

El Benni, N., & Finger, R. (2014). Where is the risk? Price, yield and cost risk in Swiss crop production. *Review of Agricultural and Environmental Studies-Revue d'Etudes en Agriculture et Environnement (RAEStud)*, *95*(906-2016-71350), 299-326.

Finger, R. (2010). Evidence of slowing yield growth–the example of Swiss cereal yields. *Food Policy*, *35*(2), 175-182.

Finger, R., & El Benni, N. (2013). Farmers' adoption of extensive wheat production–Determinants and implications. Land Use Policy, 30(1), 206-213.

Finger, R., Böcker, T., Möhring, N., & Dalhaus, T. (2016). Ökonomische Analyse des Einsatzes von Pflanzenschutzmitteln – Risikoaspekte und Lenkungsabgaben. Bericht zu Händen des Bundesamts für Landwirtschaft. ETH Zürich and University Bonn, October 2016.

Fossati, D. & Brabant, C. (2003). Die Weizenzüchtung in der Schweiz. *AgrarForschung*, 10 (11-12), 447-458.

IP-SUISSE (2021). Information retrieved from www.ipsuisse.ch (last accessed July 12th, 2021).

Migros (2020). "Migros setzt bei Brot aus der JOWA-Bäckerei auf komplett pestizidfrei angebauten Weizen", retrieved from https://www.migros.ch/de/unternehmen/medien/mitteilungen/show/news/medienmitteilungen/2020/pestizidfreier-weizenanbau.html (last accessed July 12th, 2021).

Möhring, N., Ingold, K., Kudsk, P., Martin-Laurent, F., Niggli, U., Siegrist, M., Studer, B., Walter, A. & Finger, R. (2020). Pathways for advancing pesticide policies. *Nature food*, *1*(9), 535-540.

Möhring, N. & Finger, R. (2021). Pesticide-free but not organic: the adoption of a large-scale wheat production program in Switzerland. Food Policy (*under review*).

Stamp, P., Fossati, D., Mascher, F. & Hund, A. (2014). Wie geht es weiter mit der Weizenzüchtung? *Agrarforschung Schweiz* 5 (7-8), 286-291.

Wang, Y., Möhring, N. & Finger, R. (2021). Information transmission and spillover effects in the adoption of agricultural innovations: The case of pesticide-free wheat production. (submitted).