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Innovation and Diversification through Niche Crops – Potential and Suitability for Switzerland

Master Thesis

by
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Zusammenfassung

Die Landwirtschaft muss sich weltweit an den Klimawandel anpassen. Mehrere Studien haben gezeigt, dass die Diversifizierung der Nutzpflanzen die Klimaresilienz der landwirtschaftlichen Systeme verbessern, den Einsatz von Pestiziden reduzieren und die Biodiversität fördern kann. Immer mehr Verbraucher werden sich dieser Problematik bewusst und bevorzugen lokal produzierte Produkte aus biologischer Landwirtschaft. In der vorliegenden Arbeit stellen wir einen effizienten Ablauf zur Identifizierung neuer Kulturpflanzen auf Basis der öffentlich zugänglichen Datenbanken EcoCrop und FAOSTAT der Food and Agriculture Organization der Vereinten Nationen vor und wenden ihn auf die Schweiz an. Um neue Kulturen zu identifizieren, vergleicht die Proximity Analyse die Schweizer Agrarproduktion mit der Produktion anderer Länder. Die EcoCrop-Alternative Analyse nutzt die Wachstumsbedingungen zur Identifikation neuer Kulturen. Zudem haben wir durch Interviews mit Interessenvertretern entlang der Nutzpflanzen-Wertschöpfungskette Kriterien entwickelt, welche die neuen Kulturen erfüllen müssen, um in der Schweiz erfolgreich angebaut werden zu können. Diese Kriterien umfassen eine breite Palette von Themen, die von der landwirtschaftlichen Produktion über die unterstützende Infrastruktur bis hin zu kommerziellen Kriterien reichen und wurden dann zur Bewertung der neuen Kulturen herangezogen. Diese Bewertung ergab, dass die Proximity Analyse und die EcoCrop-Alternative Analyse zur Identifizierung potenzieller neuer Kulturen für sehr unterschiedliche Anwendungen führten, von Getreide über Gemüse bis zu Obstbäumen, von denen einige nur für Nischenmärkte relevant sind und andere ein Potenzial für den Anbau in grösserem Umfang haben. Während die Proximity Analyse eine Tendenz zu Kulturen mit höherem wirtschaftlichem Potenzial aufweist, entdeckte die EcoCrop-Alternative Analyse zum Teil eher exotische Pflanzen, die sich allenfalls für Nischenmärkte eignen. Zusammenfassend liefern die beiden Ansätze zur Identifizierung von Nutzpflanzen sich ergänzende Listen neuer Pflanzen, die dann anhand der durch die Interviews definierten Kriterien weiter analysiert werden können. Da die verwendeten Datenbanken öffentlich zugänglich sind, kann der vorgestellte Arbeitsablauf global angewendet werden und möglicherweise eine Rolle bei der Diversifizierung der Landwirtschaft spielen und diese an die Herausforderungen des Klimawandels anpassen.

(For the summary in English please refer to the manuscript)

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Manuscript

The following manuscript has been prepared for submission to the journal “Agronomy for Sustainable Development”.

Adapting Agriculture to Climate Change: A Strategy for Crop Identification and Evaluation.

Stephan Gysi, Jürg Hiltbrunner, Isabel Jaisli

Abstract

Globally, agriculture has to diversify to adapt to climate change. Many studies have shown that crop diversification can improve climate resilience of agricultural systems, reduce pesticide application and promote biodiversity. Increasingly, consumers are more aware of these issues and favor products produced locally from organic agriculture. Here, we present an efficient workflow for identifying new crops based on the publicly available databases, EcoCrop and FAOSTAT of the Food and Agriculture Organization of the United Nations, and apply it to Switzerland. To identify new crops, the Proximity Analysis compares Swiss agricultural production with national production data of other countries. The EcoCrop Alternative Analysis uses conditions for growth as a tool for identification of new crops. Furthermore, through interviews with stakeholders along the crop value chain, we developed criteria which the new crops have to fulfill in order to be successfully cultivated in Switzerland. These criteria span a wide range of topics from agricultural production to supporting infrastructure and commercial criteria, and were then used to assess the new crops. This assessment indicated that the Proximity Analysis and the EcoCrop Alternative Analysis resulted in the identification of potential new crops for very varying uses, from cereals to vegetables and fruit trees, some only relevant for niche markets and others with the potential of being cultivated on a larger scale. While the Proximity Analysis has a bias toward crops with a higher economic potential, the EcoCrop Alternative Analysis discovered more exotic plants suited for niche markets. Taken together, the two approaches for crop identification deliver complementing lists of new crops that can then be further analyzed using the criteria defined through the interviews. Since the databases used are public, the presented workflow can be applied globally and may be able to play a role in diversifying agriculture, adapting it to the challenges presented by a changing climate.

1. Introduction

On a global scale, agriculture is under pressure. While it provides food for a growing world population and the average per capita energy taken up through food is increasing, the agricultural sector is, at the same time, one of the large emitters of greenhouse gases (Smith, et al., 2014) and is itself impacted intensively by climate change (Porter, et al., 2014). Looking at these impacts on a regional level, the existing models predict highly variable outcomes. Depending on where on the globe a region under study is located and the crops grown in that region, impacts of changing temperatures and precipitation are predicted to have positive and/or negative influences on agricultural productivity (Porter, et al., 2014). Therefore, it is hardly possible to apply the global trend to individual regions and regional trends are often difficult to interpret due to the high degree of uncertainty in the models. Nevertheless, if

appropriate adaptation measures are to be identified, then the regional level should be studied in an effort to prepare agriculture for a changing climate and assure that adequate food supply remains guaranteed. Multiple studies have indicated that adaptation to climate change does not solely mean selecting crops suited to higher temperatures and less precipitation, and utilizing the prolonged vegetation period optimally. Equally important is how sensitive a crop is to weather extremes which are projected to occur more frequently, potentially leading to high year-on-year variability in harvests (Smit & Skinner, 2002). Many studies focusing on how agriculture could adapt to climate change mention that choosing or breeding varieties of existing crops with higher tolerance to the local future climatic conditions as well as the identification of new crops will be an efficient path to developing a more climate resilient agriculture (Howden, et al., 2007). Di Falco and Chavas (2008) showed in a modelling study for southern Italy that high crop biodiversity is able to buffer some of the adverse effects of reduced rainfall in the short term and possibly reverse these negative effects in the longer term. Therefore, they concluded that diversification of crops is one of the fundamental requirements of a resilient agricultural system.

Apart from its positive effect on climate resilience, a diversified agriculture can also improve resource efficiency through reducing pesticide application. A more diverse cultivation regiment has a beneficial impact on insect diversity and abundance, including predator species of common pest species (Gurr, Wratten, & Luna, 2003). For example, diversification of rice cultivation with nectar providing bordering crops promoted presence of parasitoids leading to a natural reduction of insect pests and a concomitant reduction in pesticide application (Gurr, et al., 2016). However, insects are important to agriculture not only as pests or predators thereof. A recent study has shown that, on a global level agriculture is becoming more pollinator dependent and diversification of the agricultural landscape could help maintain pollination services (Aizen, et al., 2019).

In a recent report commissioned by the European Parliament the authors explored future scenarios for the agri-food sector (Ferreira, et al., 2019). They concluded that the only scenario providing adequate food to an increasing world population in a sustainable way would need cultivation techniques that preserve soil quality; require a high diversity of crops to improve resilience; should minimize inputs; and move towards organic production systems. Furthermore, they stated that, in particular, consumers in middle- and high-income countries are becoming increasingly mindful of the impact of their food purchasing decisions (Ferreira, et al., 2019). This trend can be observed in Switzerland in recent years, for example, through an increasing amount of offers of fruit and vegetable baskets, also or in particular for people living in urban areas, who are purchasing directly from the producing farmer. The strengthening of local production is also an integral part of the new Swiss agricultural policy framework AP22+ (Bundesamt für Landwirtschaft BLW, 2018). On the one hand, the aim of this framework is to increase domestic value creation in the sector by stimulating farmers to better serve customer demands. On the other hand, the ecosystem should not be overused and agricultural practices should be chosen to

support an agriculture that is adapted to local conditions. Another topic that has been receiving a lot of attention recently in Switzerland in political debates and newspaper articles is the application of pesticides. It is yet unclear what the conclusions of this debate will be but a consensus seems to appear that pesticide application should be reduced.

Taken together, these points indicate that adaptations to the way we produce food are required to face the future challenges that will impact agriculture. Crop diversification could play a major role in this process. Therefore, strategies for identifying new crops are needed. Here, we present a straight forward workflow for the identification of new crops suitable for cultivation in the region under study and a preliminary framework to test the identified crops from an agronomical perspective including ecology and economy. In a proof of concept, we then successfully applied this workflow to the agricultural system of Switzerland.

2. Materials and Methods

The presented work contains two parts. The first part is dedicated to the identification of new crops for Swiss agriculture and consists of the Proximity Analysis and the EcoCrop Alternative Analysis, which are quantitative approaches analyzing two databases provided by the Food and Agriculture Organization (FAO) of the United Nations. The second part, the stakeholder interviews, represents the qualitative part of the study to determine the criteria which the potential new crops have to fulfill. Some of these criteria are then used in the Suitability Assessment for a preliminary quantification of the suitability of the potential new crops for the Swiss agricultural system. The workflow depicting the interdependence of the different steps is illustrated in figure 1.

2.1 Identification of New Crops

2.1.1 Proximity Analysis

The Proximity Analysis is based on the concept of the product space established by Hidalgo et al. (2007). The Swiss agricultural product space is defined as all crops reported to be cultivated in Switzerland in 2018. The underlying concept of the Proximity Analysis is that crops, which are cultivated in countries other than Switzerland together with one of the crops of the Swiss agricultural product space, need similar conditions for growth as the Swiss crop and could, therefore, be cultivated in Switzerland too. To perform the Proximity Analysis the following data are required:

a) List of crops grown in the Swiss agricultural product space, hereafter referred to as reference crops.
b) List of crops grown in all countries except Switzerland

The data which defines the Swiss agricultural product space was retrieved from the Swiss Federal Statistical Office (Federal Statistical Office, 2019), the Schweizerische Zentralstelle für Gemüsebau und Spezialkulturen (SZG) and the annual report of the Schweizer Obstverband (SOV) (Schweizer

Obstverband, 2018). Since the study focusses on open agricultural spaces, data from crops grown in greenhouses were excluded from the analysis.

On FAOSTAT, the various agricultural products are called "items". These items usually represent one species or variety. In some cases, however one item represents a group of taxonomically related species (for a description of the FAO agricultural product items please refer to "definitions and standards" on FAOSTAT (2019)). Therefore, for all Swiss reference crops, the corresponding FAO item was searched to compile the final list of reference crops to be used in the Proximity Analysis.

The data on crops grown in all countries except Switzerland were obtained from the FAOSTAT database "Value of Agricultural Production" of the FAO (FAOSTAT, 2019). For all countries contained in the database, data on all agricultural products (items) are provided. The focus of this study are food crops. Therefore, all non-plant items were excluded and, for all countries, all plant related items (crops) for the year 2016 (being the newest data available) and the Gross Production Value (GPV, current million US$) were downloaded.

The procedure of the Proximity Analysis is schematically shown in figure 2 and follows five steps.

- Step 1: For one particular reference crop, all countries (except Switzerland) in which it is cultivated are searched in the FAOSTAT dataset.
- Step 2: For all countries identified in step 1, all crops cultivated are assembled in one list.
- Step 3: A count of how often one particular crop appears in the list from step 2 is performed. This leads to a proximity list specific for one reference crop.
- Step 4: Step 1 to 3 are repeated for every reference crop.
- Step 5: The different reference crop specific proximity lists are summed up, resulting in the product space specific proximity list.

A high score for a crop indicates that this crop is often cultivated together with one of the reference crops. The higher the score, the lower the proximity. If a reference crop and a new crop have a low proximity, they are considered to need similar conditions for growth.

This procedure was performed twice. The first was with crops from the FAOSTAT dataset with a GPV of more than $100,000 and the second was without such a limit. The data analysis was performed using the software R (R Core Team, 2018) and the package "tidyverse" (Wickham, 2017). The list of reference crops as well as the complete proximity list can be obtained from the authors.

2.1.2 EcoCrop Alternative Analysis

In order to diversify the procedure for identification of new crops, a second approach using the FAO database EcoCrop (FAO, 2003) was performed. EcoCrop is a database containing more than 2,000 crops and for every crop, environmental conditions (soil and climate) and indications about uses are assembled in a data sheet. From this data sheet, one can obtain a list of alternative crops favoring similar conditions. This list of alternatives was retrieved for all Swiss reference crops and a frequency count

was performed on how often a certain alternative crop appeared in these lists of alternatives. This led to a long list of crops for different kind of uses. Subsequently, only crops listed as food crops in EcoCrop were retained. For a total of 82 reference crops alternative crop lists were obtained. A complete list of reference crops and the identified alternatives can be obtained from the authors.

In order to further filter the crops identified in the two approaches and select the most promising crops, the following filters were applied to all the potentially new crops identified:

- Unspecific crop name: the crop names identified in the analyses need to be specific for one crop. Sometimes, crop names refer to a group of taxonomically related species that do not all need the same conditions for growth. Therefore, unspecific crop names were excluded.
- Poor frost tolerance: Perennial crops need to be frost tolerant in Switzerland. Particularly evergreen fruit trees have to be excluded from further analysis since these trees would not survive strong freezing and would likely collapse when there is snowfall.
- Already cultivated in Switzerland: The reference crop lists are by default only containing crops, which are officially reported to be grown in Switzerland. There are crops which are regularly grown on a small scale but are not reported. While such crops are excluded from further analysis, they represent positive controls, indicating that relevant crops are being identified.

After applying these filters, the final list of new crops was compiled.

2.2 Stakeholder Interviews

In order to determine the criteria, which the new crops have to fulfill in order to have a good chance to be adopted by Swiss farmers, 15 semi-structured interviews were carried out following the guidelines by Adams (2015). The interview partners were chosen through targeted case selection (Helfferich, 2011) in order to represent the entire crop value chain as well as research institutions and policy makers as shown in figure 1. The selection was made to represent as many different opinions as possible from small organisations caring only about niche crops to large organisations focussing on the major Swiss crops and from organic to conventional agriculture.

The semi-structured interviews were carried out using an interview guide and were divided in two parts. First, the stakeholders were asked to define general criteria new crops would have to fulfill without focussing on their core topic. Then, the same question was asked with a focus on their expertise and interview partners were encouraged to make concrete examples from their own experience. The interviews were recorded and transcribed on a word by word basis and all comments representing a criterion were extracted. Subsequently, the comments were grouped by topic, with every topic representing one criterion and a detailed description of the criterion was established containing all comments made by stakeholders.

2.3 Suitability Assessment

The Suitability Assessment is designed to deliver a preliminary evaluation of the potential new crops. A literature search was performed for the new crops with the aim of evaluating them according to the criteria defined through the stakeholder interviews.

3. Results and Discussion

3.1 Identification of New Crops

3.1.1 Proximity Analysis

The result of the Proximity Analysis is summarized in table 1 with the top 30 potential new crops sorted according to their proximity to the agricultural product space of Switzerland. These crops were then subjected to the final filtration step to select for the most relevant new crops. Therefore, the following crops were excluded, ordered by the filter applied:

- Unspecific crop name: “Beans dry”, “Beans green”, “Pulses nes”, “Nuts nes”, “Fruit citrus nes”, “Cereals nes”, “Spices nes”, “Anise, badian, fennel, coriander” (purple items in table 1)
- Poor frost tolerance: “Oranges”, “Lemons and limes”, “Tangerines mandarins clementines satsumas”, “Bananas”, “Grapefruit (incl. pomelos)”, “Sugarcane”, “Mangoes mangosteens guavas”, “Avocados”, “Papayas”, “Pineapples”, “Olives”, “Cassava” (green items in table 1)
- Already cultivated in Switzerland: “Sweet potatoes”, “Chick peas”, “Cherries sour”, “Chillies and peppers dry”, “Onions shallots green” (red items in table 1)

After this filtration step, the following items representing potential new crops remain: “Watermelons” (*Citrullus lanatus*), “Groundnuts with shell” (*Arachis hypogaea*), “Figs” (*Ficus carica*), “Almonds with shell” (*Prunus dulcis*), and “Sesame seed” (*Sesamum indicum*).

To test for robustness of the approach, Proximity Analyses were performed for different regions of Switzerland. The results from region to region were surprisingly similar despite the fact that the number of reference crops varied significantly between regions (data not shown). Furthermore, excluding crops with a GPV in their corresponding country of less than $100,000 in the FAOSTAT dataset only introduced minor changes to the ranking of the potential new crops. These observations indicate that the analysis is very robust and will deliver meaningful results even for rather small amounts of reference crops. Nonetheless, there are a few caveats linked to this analysis. Firstly, the accuracy of the data provided by FAOSTAT depends on the accuracy of the data provided by each individual country to FAOSTAT. Sometimes, only estimates could be used due to the absence of measured data. Due to the large number of countries present in the database, such negative effects will be balanced and should not influence the results adversely. Secondly, due to the nature of the analysis, crops grown only in a small number of countries will never receive a high score and low proximity to the Swiss agricultural product space. Therefore, the Proximity Analysis has a certain bias towards crops with relevance in a large number of countries.

3.1.2 EcoCrop Alternative Analysis

The EcoCrop Alternative Analysis resulted in a long list of crops for very different uses. After excluding all non-food crops, a total of 15 food crops remained, each with at least 20 appearances on an alternative crop list (table 1). These crops were then subjected to the final filtration step to select the most relevant new crops. The following crops were excluded:

- Unspecific crop name: beet (*Beta vulgaris*) (purple crop in table 1)
- Poor frost tolerance: carandas plum (*Carissa carandas*), Suriname cherry (*Eugenia uniflora*), Strawberry guava (*Psidium cattleianum*), longan (*Dimocarpus longan var. long*), climbing num-num (*Carissa edulis*) (green crops in table 1)
- Already cultivated in Switzerland: rutabaga (*Brassica napus var. napobrassica*), black mustard (*Brassica nigra*), physalis (*Physalis peruviana*) (red crops in table 1)

Hence, the potential new crops identified by the Alternative Analysis are foxtail millet (*Setaria italica*), oysternut (*Telfairia pedata*), hairy eggplant (*Solanum ferox*), fluted pumpkin (*Telfairia occidentalis*), yellow Guinea yam (*Dioscorea cayenensis*), and chayote (*Sechium edule*).

The list of potential new crops from the Alternative Analysis complements the crops identified through the Proximity Analysis. While the Proximity Analysis is based on actual production data, the Alternative Analysis is entirely based on conditions for growth as present in the different data sheets of the reference crops in EcoCrop. Therefore, the Alternative Analysis does not contain a bias like the Proximity Analysis and is exclusively relying on the accuracy of EcoCrop data. On the other hand, the bias of the Proximity Analysis on globally frequently cultivated crops also means that crops with a higher economic relevance are selected. Indeed, all crops identified in the Proximity Analysis are crops imported to Switzerland (Swiss Federal Customs Administration FCA, 2019). This contrasts the results of the Alternative Analysis that discovered crops which will most likely be unknown to most Swiss consumers. Taken together, the two approaches offer the opportunity to identify a wide range of potential new crops. Some of these crops will be an option for small niche markets whereas others have the potential to reach the broader market. To unleash this potential, the identified new crops will need to be tested extensively in subsequent studies to find suitable cultivars for Swiss agriculture or to be used in breeding programs with the aim of cultivating a well-adapted variety.

3.2 Stakeholder Interviews

In order to provide a further assessment tool for the new crops, interviews were conducted to define criteria the new crops should fulfill. The analysis of these stakeholder interviews resulted in 11 criteria with detailed descriptions. Thematically the criteria can be subdivided into three topics:

- Agriculture: “Crop rotation”, “Suitability for cultivation and climate resilience” and “Resource-saving cultivation” have a direct impact on agriculture;

- Supporting systems: “Incentives”, “Networks”, “Technology” and “Breeding and seeds” focus on supporting systems, positively impacting the value chain at different stages; and
- Commercial: “Communication”, “Market and customer demands”, “Quality” and “Economic viability” deal with issues relevant for commercial purposes.

3.2.1 Agriculture

Crop rotation:

Generally, a new crop should contribute to the diversification of the crop rotation by offering an alternative to some of the main Swiss cultures (e.g. wheat, maize, sugar beet). It should either fit into the established crop rotations or, together with multiple new crops, form a new crop rotation. At the same time, a new crop should not displace the main crops to such a degree that their acreage is reduced excessively, which would then lead to increased imports. Furthermore, the new crop should also fit into the established crop rotations with regards to cultivation technique.

Suitability for cultivation and climate resilience:

The new crop has to be adapted to the (changing) climatic conditions and the soil in Switzerland. A short vegetation period could be an advantage to reduce the impact of climate variability/extremes. Tolerance to intensive precipitation, droughts and periods of intensive heat are important. Agronomically, the cultivation of the new crop should not be difficult.

Resource-saving cultivation:

A new crop will need to be relatively easy to cultivate and will need to be competitive in its growth properties to counteract weed infestation of crop lands, particularly during the early development of the plants. Pesticides should not play an important role in cultivation and, if unavoidable, organic pesticides should be available (no synthetic pesticides). Also, with regards to fertilization and irrigation the new crop should not be demanding - it should not overuse the soil and, if possible, support biodiversity. Basically, a new crop should be adaptable to organic farming practices and increase the efficiency of the entire system (crop rotation). If the new crop is replacing imports, the question whether local production is really less resource-intensive than imports should be considered very carefully.

3.2.2 Supporting systems

Incentives:

Incentives from governmental agencies or the private sector can play a role when introducing a new crop to instigate research or breeding programs and for farmers to reduce their financial risk. Organizations from the private sector could, for example, issue assurances that the harvest will be received. Governmental agencies could support programs for breeding and research on the one hand

while on the other, subsidies and regulation of imports and import taxes can play an important role to protect local production from cheaper imports. Additionally, such measures help to use the capacities of the local processing infrastructure at economic levels. However, subsidies and import regulations should only be established if there is a need. If a crop can be sold for a sufficient price on the open market, financial support of production is unnecessary.

Networks:
For new crops, information availability is often limited, making the distribution of information essential. Pioneering farmers could share their experience. Organizations such as seed companies could provide advice to farmers and collect experiences from their customers or gather information from abroad and available research to provide optimal advice to farmers. Information about optimal cultivars, plant protection measures, cultivation, and processing of the harvest should be distributed. Knowledge sharing between farmers could also help solving problems during cultivation.

Technology:
During every step in the value chain, there are processes that need to be efficiently performed. During cultivation, the mechanization of sowing, care and maintenance are relevant and, if possible, should not require the farmer to buy new equipment. Often, the first processing step (crop collection point) is problematic. The collection points have to be ready to receive the new crop and clean, or ventilate, the harvest if necessary. The collection points should either not be far away from production in order to provide the infrastructure for storage after harvest or the new crop needs to have good storage properties. It is essential that the technical infrastructure for all steps in the value chain are either readily available or can be developed to keep the entire value chain functioning. Often, there is one step in the value chain that requires the knowledge of a key technology that has to be mastered.

Breeding and seeds:
The availability of genetic diversity in the new crop is important to establish breeding programs, e.g. to improve uniformity of ripening, quality of harvests or resource efficiency (e.g. via resistances to diseases) through breeding. Access to genetic resources abroad needs to be granted. If suitable cultivars exist, access to quality seeds needs to be guaranteed. Alternatively, local seed production has to be established.

3.2.3 Commercial

Communication:
The added value that can be achieved due to local production and a potential reduction of imports should be communicable to customers to explain the (usually) higher prices of local Swiss production. It is

very efficient and credible if this information is not only provided by retailers but also through other sources such as nutritionists.

Market and customer demands:
Fundamentally, one needs to distinguish between different marketing strategies. If a new crop is primarily marketed directly by the farmer or in smaller stores with a focus on organic and niche products, a special agricultural product will be found by specialized customers looking for local products and ready to pay a higher price. However, if the crop is being cultivated on larger acreage, then the existence of a broader customer demand is relevant. The crop should be able to serve a longer-term trend. It is often helpful to have a driving force in the market, such as a large retailer wishing to complement its selection of products, e.g. by replacing imports through locally produced goods. The product should represent an innovation offering the retailer an opportunity to distinguish itself from other retailers. Reaching a certain acreage can be beneficial to render the establishment of processing infrastructure worthwhile, particularly if complicated processing steps are required.

Quality:
The quality has to fit the demand. In order to reach the mass market in Switzerland with a locally grown crop, the quality has to be consistent and excellent in comparison to imported equivalents to justify the price difference. This could, for example, be achieved by promoting a healthy substance of content. The quality has to be maintained throughout the entire supply chain and be stable across multiple years.

Economic viability:
The consumers have to be ready to pay a premium for a product that is produced in Switzerland. The price should be high enough to guarantee a fair price to farmers to cover their expenses and to allow for future investments. If the crop is only marketed on a small scale through specialized organic retailers, then the difference in price between the local produce and the import is not very important. However, if a larger market should be reached via general retailers, then the difference in prices should not be large. The retailer should be able to reach a good margin and the product should fit its overall concept.

Taken together, these criteria provide an overview of topics, which are either current or longstanding points of discussion in Swiss agriculture. A recurring topic are the high prices for production in Switzerland compared to even its closest neighbors - Italy, France, Germany or Austria. Swiss farmers are exposed to intensive price pressure from imported agricultural products, which is why subsidies, regulation of imports and the willingness of the Swiss customers to pay a premium for local production are repeatedly mentioned in the criteria. Even if these are certainly issues very specific to agriculture in Switzerland, they can be generalized and transferred to other countries too. A reasonable amount of

protection of local production could be beneficial for the establishment of a new value chain also for countries operating on a lower price level. Another topic, which is currently intensively discussed in Swiss politics is represented by the criterion "Resource-saving cultivation". Interviewed stakeholders from practically all domains, whether focusing on organic agriculture or not, were quite clear about the fact that agriculture has to be less resource intensive in the future, particularly with regards to pesticide application. Furthermore, it is interesting to note that some criteria, such as "Market and customer demands" are mentioned by all stakeholders, which is not surprising since everybody, regardless of the size of the organization, needs to be able to sell their products. In contrast, other criteria such as "Quality" have only been mentioned by two large Swiss retailers. For them, this is a crucial point, indicating that in order to reach the broader market, one needs to be able to provide high quality consistently. This is contrasted by a situation where a farmer sells products through direct marketing, reaching customers who place a higher value on local production and are prepared to accept a different quality than found in a supermarket. Overall, the criteria could be applied to different countries with some adaptations to local conditions.

3.3 Suitability Assessment

The aim of the Suitability Assessment is to deliver a first evaluation of the new crops based on publicly available information according to the criteria of the stakeholder interviews. Since the criteria cover a very wide range of topics and the crops can be used for a wide range of purposes, from cereals to vegetables and fruits, it is impossible to perform a thorough evaluation of all crops and all criteria based on a literature search. In-depth analyses, specific for individual crops including field trials to identify promising varieties, will have to be performed in the future.

3.3.1 Watermelon, *Citrullus lanatus*

For many years, watermelons have been very popular in Switzerland in summer, illustrated by strongly increasing imports from about 8,300 t in 1996 to about 30,700 t in 2018 (Swiss Federal Customs Administration FCA, 2019). Roughly half of the annual imports come from Italy. Other significant exporters to Switzerland are Spain, Morocco and Greece. There are reports of pioneering farmers planting the variety "Swiss Melody" successfully in Switzerland (Eppenberger, 2018). "Swiss Melody" produces small fruits of about 1.5 kg, which are quite sweet and do not contain many seeds. Its cultivation is reported to be rather difficult and it was mentioned that marketing was challenging. The EcoCrop data sheet for watermelons indicates that the plant would be suited to the Swiss climate if summers were to become hotter and dryer. However, longer periods of intensive rain could be problematic, leading to excessive vegetative growth, leaf diseases and fruit rot (FAO, 2003). If breeding efforts could create varieties that are easier to cultivate in Switzerland, this crop could have a chance to be grown locally replacing some of the imports.

3.3.2 Groundnuts, *Arachis hypogaea*

Traditionally, groundnuts with shells are highly appreciated by Swiss customers in December and January but also shelled and with different flavors all year long. While the plant could potentially be suited for cultivation in Switzerland (FAO, 2003) there is only one report in a local newspaper of two pioneering farmers succeeding with cultivation, albeit with difficulties (Lenzin, 2018). Interestingly, almost half of the 7,500 t that were imported in 2018 were unroasted (Swiss Federal Customs Administration FCA, 2019). Indeed, there are a number of groundnut-roasteries in Switzerland, some small and serving specialized markets but also large companies roasting groundnuts for the large retailers. Should a future local production be established, these roasteries could provide some of the required infrastructure. In order for production to succeed, the choice or breeding of well-adapted varieties will be crucial.

3.3.3 Figs, *Ficus carica*

Fig trees can be observed in Swiss gardens quite frequently. EcoCrop finds figs to be fit for Swiss conditions (FAO, 2003) and pioneering farmers are already cultivating the tree. A number of varieties have been found to grow and fruit well in Switzerland. The choice of a well-adapted cultivar is crucial for successful Swiss cultivation (Boos & Husistein, 2004). Figs are imported to Switzerland fresh and dried (Swiss Federal Customs Administration FCA, 2019). Locally produced figs could have a competitive advantage over imports of fresh figs. Due to the softness of the mature fruit, fresh figs from abroad need to be harvested slightly before reaching full maturity. Locally produced figs could be harvested at full maturity since transportation distances are much shorter than for imported fruits.

3.3.4 Almonds, *Prunus dulcis*

Almonds are recently receiving interest from farmers and researchers in Switzerland (personal communications) but reports of successful production are still missing in the public domain. Nevertheless, there are a few tree nurseries offering a selection of varieties. According to unchecked claims of these nurseries, these varieties exhibit good frost tolerance and are suited for cultivation in Switzerland. A farm in the southern German part of the Rhein valley claims to have successfully grown almonds in the last few years (www.mandelhof-freinsheim.de), indicating that there could be a potential for cultivation in Switzerland too. More than half of all almonds imported to Switzerland in 2018 came from the USA (Swiss Federal Customs Administration FCA, 2019). However, US almond production is linked to overuse of natural water bodies and high pesticide application killing many of the bees needed for pollination (Philpott, 2014). This could offer opportunities for a resource-saving almond production in Switzerland.

3.3.5 Sesame, *Sesamum indicum*

While sesame is one of the important oil crops globally, there have been only very limited breeding efforts. Recently, however, this has changed with breeding programs to improve, for example, yield, disease resistance or mechanized harvesting made possible due to the advent of modern genomic research (Dossa, et al., 2017). Most of the sesame imported to Switzerland comes from India (Swiss Federal Customs Administration FCA, 2019). Small scale production exists in Europe in Italy, Greece and Bulgaria (Dossa, et al., 2017). According to EcoCrop, the plant could be relatively well suited for Swiss conditions and, in a changing climate, its tolerance to drought could be positive for cultivation in Switzerland (FAO, 2003). Therefore, while it is questionable if a variety fulfilling Swiss criteria already exists, future breeding programs could result in the establishment of such a cultivar.

3.3.6 Foxtail Millet, *Setaria italica*

While different types of millets are eaten in Switzerland, an Internet search for foxtail millet indicates that it is mainly sold as pet food. Nevertheless, this crop could have a good potential for cultivation in Switzerland. It is one of the oldest crop plants cultivated in many parts of the globe. It tolerates dry conditions and seeds mature within 80 to 120 days from sowing (Hermuth, et al., 2016). EcoCrop describes the conditions for growth as well adapted to Swiss conditions (FAO, 2003) and foxtail millet's tolerance of drought make it suited for a changing climate. Breeding efforts in the Czech Republic have led to new varieties that could be cultivated in Switzerland too (Hermuth, et al., 2016).

3.3.7 Oysternut, *Telfairia pedata* and Fluted Pumpkin, *Telfairia occidentalis*

Oysternut and fluted pumpkin are two tropical, perennial vines primarily grown in Africa for their nutritious seeds. There is limited information about conditions for growth, but they are probably not frost tolerant (FAO, 2003). *Telfairia occidentalis* can be grown as an annual plant for its young shoots and leaves. No imports to Switzerland are reported for the two plants (Swiss Federal Customs Administration FCA, 2019) indicating that there is probably no economic potential.

3.3.8 Hairy Eggplant, *Solanum ferox*

The fruits of the hairy eggplant are used in Asia in curries. The limited information available indicates that, while it is a perennial, it could be cultivated as an annual plant. Conditions in Switzerland are probably not suitable (FAO, 2003). Since there are no imports to Switzerland (Swiss Federal Customs Administration FCA, 2019) there is probably no economic potential.

3.3.9 Guinea Yam, *Dioscorea cayenensis*

Yam (*Dioscorea spp.*) is an important tuber crop in Africa containing many different species. In 2018, about 160 t were imported to Switzerland, mainly from Ghana with minor quantities from France and

Italy (Swiss Federal Customs Administration FCA, 2019). The agronomic potential for *Dioscorea cayenensis* is limited in Switzerland (FAO, 2003). Other *Dioscorea* species offer some potential. In a report in the Swiss farmers newspaper, cultivation of *Dioscorea batatas* is described (Stückelberger, 2019). Therefore, selection of the best species may be key to yam cultivation in Switzerland.

3.3.10 Chayote, *Sechium edule*

According to a number of short Internet reports, the chayote has received some interest from hobby gardeners. Additionally, it grows on the campus of our university indicating good conditions for growth of chayotes in Switzerland. However, it is unknown to most Swiss consumers and could, therefore, most likely only be used in niche markets.

Taken together, these preliminary suitability assessments show that the crops identified in the Proximity Analysis have a better potential than the ones identified in the EcoCrop Alternative Analysis. The bias of the Proximity Analysis for crops with a high global importance could, therefore, be beneficial to identify crops that are already known to the consumers and for which there is abundant information available. Some of the crops identified in the EcoCrop Alternative Analysis are not well described and more work would need to be done to test their agronomic suitability. For all the identified crops, breeding efforts could be pivotal to establish cultivars with adequate suitability to cultivation conditions in Switzerland.

4. Conclusion

In this article we are presenting a method for identifying new crops in a given region and an assessment strategy for preliminary evaluation of the new crops. The procedure for crop identification is based on two publicly available databases of FAO and can, therefore, be replicated for virtually every country worldwide. As a starting point for these analyses, a precise understanding of the current agricultural system in the region under study is needed. In our case we sought to obtain detailed production data for all crops currently grown in Switzerland from official Swiss sources instead of using the data for Switzerland provided by FAOSTAT, which we found to be less up to date. The logic behind this decision was that a more precise definition of reference crops would lead to more precise results. However, using the FAOSTAT data to define the reference crops for Switzerland instead would not have impacted the results dramatically, since the approach is quite robust. The only disadvantage would have been that more crops that are already cultivated in Switzerland would have been detected as “new crops” because the FAOSTAT data is not as up to date as the data we were able to accumulate from official sources. Despite this slight disadvantage, the resulting truly new crops would have been virtually identical. Therefore, we conclude that the Proximity Analysis can be performed even in the absence of detailed production data from national sources and can rely exclusively on FAOSTAT data.

The same principle holds true for the Ecocrop Alternative Analysis. In this case too, detailed knowledge about reference crops will improve the specificity of the results but the analysis could equally be performed using FAOSTAT data for defining the reference crops. Our attempt to obtain more localized results for the Proximity Analysis by establishing lists of reference crops specific for different regions of Switzerland was not successful. Nevertheless, should the study be performed for a country with strongly differing agricultural regions, focussing on the individual region instead of the country as a whole should be considered.

Despite the robustnes of the approaches, the primary results of both analyses need to be discussed in detail. As mentioned above, the primary list of potential new crops of both approaches contained many crops with poor suitability for agriculture in Switzerland. As an example for such crops, the numerouse evergreen fruit trees can be mentioned. While it may be possible to grow them in controlled greenhouse conditions, they could rather not be cultivated on open spaces. This clearly indicates that in order to extract the most meaningful new crops from the primary results list, detailed knowledge about local farming conditions is required. If this is done with care, new crops can be identified indicating that the same procedure offers equal opportunities for countries other than Switzerland. The presented approach lays the foundation for further studies aimed at identifying suitable cultivars or designing a breeding program for the new crops. These subsequent studies would need to focus on breeding new cultivars or testing and selecting existing ones to establish recommendations to farmers on the variety to cultivate and what their conditions for growth are.

Once potential new crops are identified, the question arises - what criteria do these crops need to fulfill in order to be successfully integrated in the Swiss agricultural system. The interviews conducted to discover these criteria were designed to cover a wide range of different stakeholders along the crop value chain from production to processing and retail, from small to large organizations and some with a focus on organic farming while others practice conventional farming. Furthermore, stakeholders from crop breeding, research and policy making were included. While the detailed descriptions of the resulting 11 criteria certainly cover some topics specific to Swiss agriculture, the overall content of the criteria can be adapted to other countries to perform a preliminary suitability assessment. Such an assessment can help to prioritize the new crops for follow up studies. In such subsequent research, individual crops would need to be tested in detail.

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Figure 1:

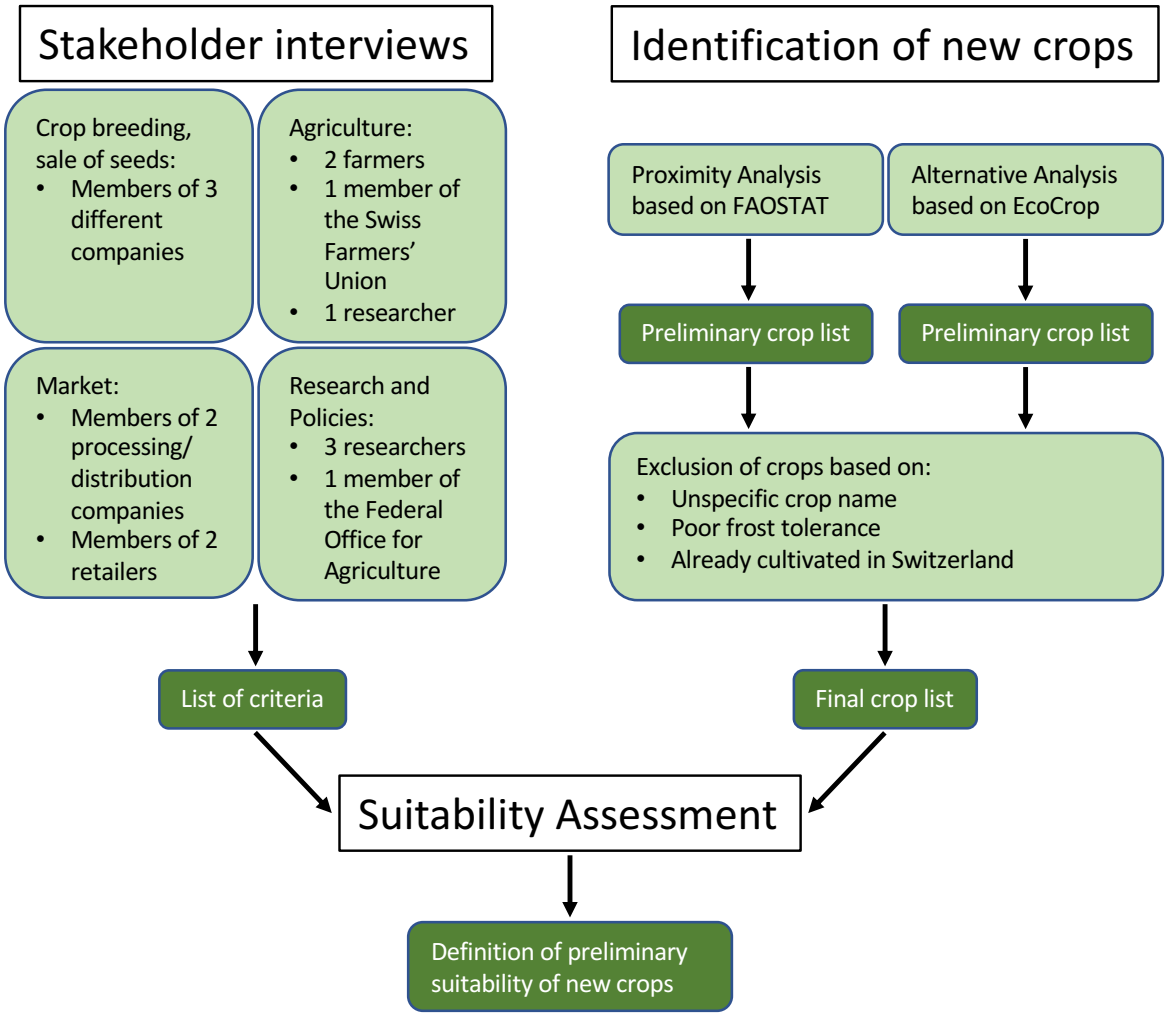

Figure 1: Workflow showing the interdependencies of the different steps of the project. The list of criteria established through the stakeholder interviews and the final list of newly identified crops serve as input to the suitability assessment, where the most promising new crops are selected.

Figure 2:

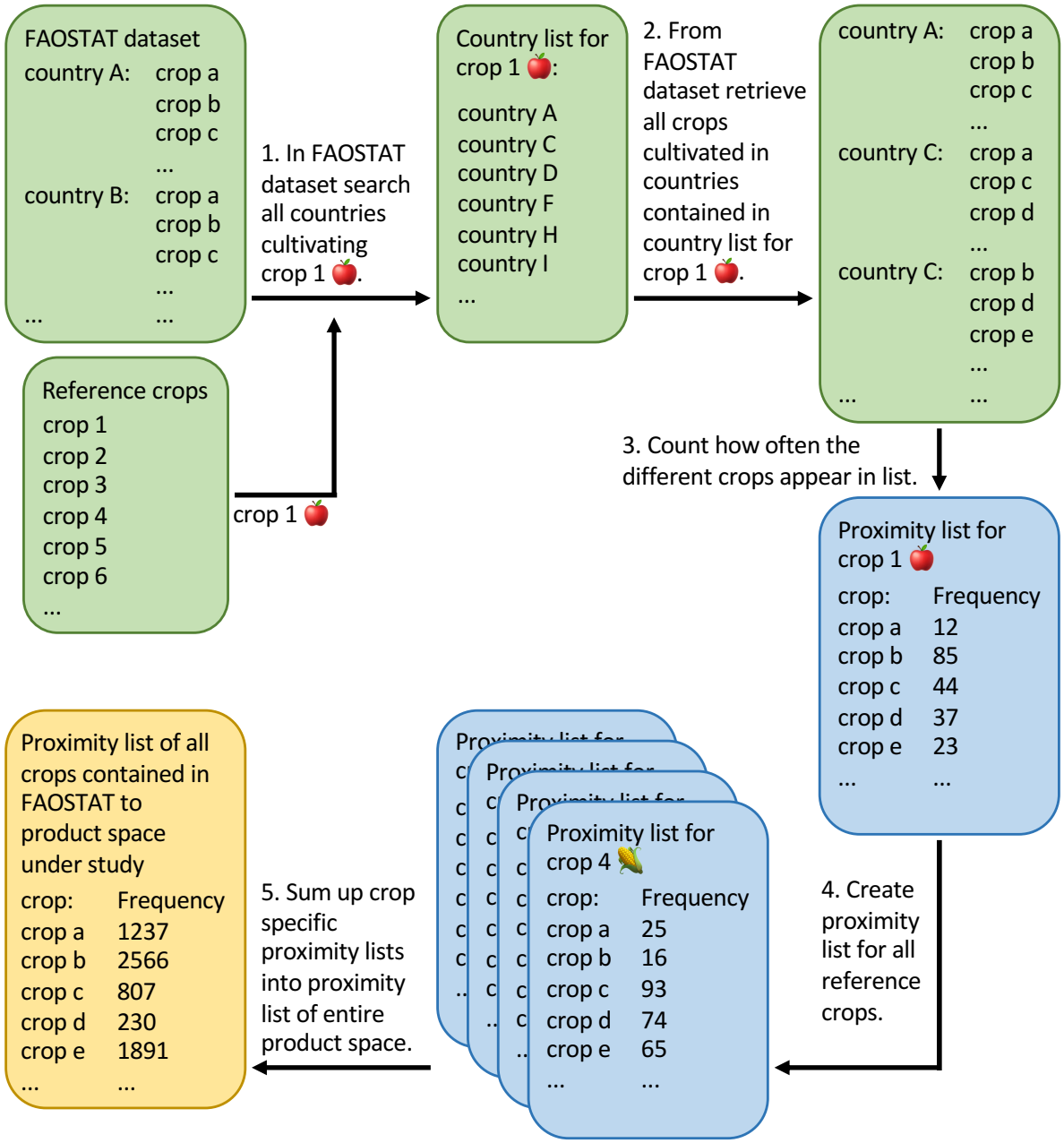

Figure 2: Schematic representation of the workflow of the Proximity Analysis. Steps 1 to 3 are repeated for every reference crop to establish reference crop specific proximity lists, which are then summarized in step 5 to result in the proximity list of the product space under study.

Table 1: Crops identified in the Proximity Analysis and the EcoCrop Alternative Analysis. The coloring of the crops indicates their classification according to the final filtration step. Purple: unspecific crop name; green: poor frost tolerance; red: already grown in Switzerland; black: final, newly identified crops

Proximity Analysis	**Ecocrop Alternative Analysis**
Beans, dry	Beta vulgaris
Beans, green	Setaria italica
Watermelons	Brassica napus var. napobrassica
Oranges	Brassica nigra
Pulses, nes	Carissa carandas
Lemons and limes	Eugenia uniflora
Groundnuts, with shell	Psidium cattleianum
Bananas	Telfairia pedata
Tangerines, mandarins, clementines, satsumas	Dimocarpus longan var. long
Sweet potatoes	Physalis peruviana
Nuts, nes	Solanum ferox
Chick peas	Carissa edulis
Grapefruit (inc. pomelos)	Telfairia occidentalis
Figs	Dioscorea cayenensis
Sugar cane	Sechium edule
Mangoes, mangosteens, guavas	
Fruit, citrus nes	
Chillies and peppers, dry	
Almonds, with shell	
Onions, shallots, green	
Cereals, nes	
Avocados	
Pineapples	
Papayas	
Sesame seed	
Spices, nes	
Cherries, sour	
Olives	
Anise, badian, fennel, coriander	
Cassava	

Appendix 1: Proximity Analysis – Additional Material

A1.1 Additional Materials and Methods

A1.1.1 Local Production Data

The data to define the Swiss agricultural product space, as described in the manuscript, are split by canton and for every crop the acreage (in hectars) in the corresponding canton is given. In an attempt to obtain more localized results for the Proximity Analysis, apart from Switzerland as a whole, a list of reference crops was established for each canton and supracantonal region. The supracantonal regions contain the following cantons (Valais and Ticino were treated separately, since their list of reference crops contained some species only cultivated in Valais or Ticino):

- Mittelland: Bern, Zurich, Solothurn, Aargau, Fribourg, Basel Land, Basel Stadt
- Eastern Switzerland: Appenzell Innerrhoden, Appenzell Ausserrhoden, Glarus, Schaffhausen, Thurgau, St. Gallen, Grisons
- Western Switzerland: Geneva, Vaud, Jura, Neuchâtel
- Central Switzerland: Lucerne, Zug, Schwyz, Nidwalden, Obwalden, Uri
- Valais
- Ticino

To focus on crops with a certain importance in their region crops grown on less than 1 ha in the area under study were excluded from further analysis. Some of the small cantons only cultivate a very small number of crops on more than 1 ha. The following cantons were therefore excluded from individual analysis: Appenzell Innerrhoden, Appenzell Ausserrhoden, Glarus, Basel Stadt, Nidwalden, Obwalden and Uri. The data of these cantons were only included in the analysis of the supracantonal regions and Switzerland as a whole. The lists of reference crops for all cantons are shown in table A1, for the supracantonal regions in table A2 and for Switzerland in table A3.

The procedure of the Proximity Analysis was repeated for each canton, supracantonal region and Switzerland as a whole, with and without applying a limit of $100,000 to the Gross Production Value.

A1.1.2 R-Script

As mentioned in the manuscript the data analysis was performed using the statistics software R. Two csv files have to be prepared containing the data input:

- reference_crops.csv: File containing the reference crops of the country to be studied. This file does not need to be prepared in cases where the reference crops are not defined based on national data sources but instead data from FAOSTAT is used.
- FAOSTAT_data: The file containing production data of all crops of all countries, can be retreived from http://www.fao.org/faostat/en/#data/QV with the following settings:
  - countries: select all
  - items: select all plant related items

- elements: Gross Production Value (current million US$)
- years: 2016 (or newer if available)

The following R-script was used for data analysis. Before running the script replace the term “country of interest” with the name of the country you are studying retaining the quotation marks:

```
library(tidyverse)

# Import file containing FAOSTAT data.
data <- read.csv("FAOSTAT_data.csv")

# Filter for crops with Gross Production Value (GPV) above 100'000$.
# This step can be skipped if no limit is applied to GPV.
# If this step is skipped replace "data_filtered" by "data" in all the    following lines.
data_filtered <- filter(data, Value > 0.1)

# Import file containing reference crops.
b1 <- read.csv("reference_crops.csv")

# Make sure the column name of b1 is "Item" and read reference crops into a vector.
colnames(b1) <- "Item"
v <- b1["Item"]

# The following step is designed to assure the reference crops are defined as Factor with the same am
ount of levels as the crops of the FAOSTAT data.
b1_a <- filter(data, Area == "country of interest" & Item == "Apples")
y1_a <- b1_a["Item"]
y1 <- replace(y1_a,1:length(v),v)

# Exclude the country of interest (Switzerland in the present study) form the FAOSTAT dataset.
d1 <- filter(data_filtered, Area != "country of interest")

# Prepare the file where the results will be stored. This file is called     "summary".
d1_Item <- as.data.frame(unique(d1$Item))
colnames(d1_Item) <- "crop"
d1_Item_alphabetically <- d1_Item[order(d1_Item$crop),]

summary <- as.data.frame(d1_Item_alphabetically)
colnames(summary) <- "crop"

# Loop to perform Proximity Analysis for all reference crops and write    each reference crop specific
proximity list in one column of the summary  file.
for (i in 1:length(y1)){
  e <- filter(d1, Item == y1[i])
  z <- e["Area"]
  f <- filter(d1, Area %in% z)
  g <- as.data.frame(table(f["Item"]))
  summary[,(i+1)] <- g$Freq
}
```

```
# Write the summary file into a csv file. The further analysis of the     results can be done in Excel.
write.csv(summary, file = "summary.csv")
```

In cases where the reference crops are not defined through separately obtained national data and data from FAOSTAT are used instead the part from definition of b1 until definition of y1 can be replaced by:

```
# Extract reference crops from FAOSTAT data.
b1 <- filter(data_filtered, Area == "country of interest")
y1 <- b1[,"Item"]
```

A1.2 Additional Results and Discussion

The results for the different regions were surprisingly similar despite the fact that, in particular the number of reference crops varied significantly between regions (from 21 for the canton of Jura to 67 for Switzerland). To illustrate this the results of Jura (21 reference crops) and Zurich (51 reference crops) are shown in table A4. Furthermore, applying the limit of $100,000 to the Gross Production Value (GPV) of the FAOSTAT dataset did not change the results dramatically. Table A4 contains results for Jura and Zurich once with and once without applying the limit.

Through the application of the Proximity Analysis on different geographic entities within Switzerland (cantons, supracantonal region and whole Switzerland) we were able to show that the analysis is fairly robust indicated by the largely overlapping results for the different geographic boundaries. The same holds true for applying a limit to GPV. For all these different approaches the newly identified crops remained more or less stable. Only their ranking changed slightly. A high ranking indicates a low proximity to the product space under study. Table A5 shows the complete proximity list for Switzerland.

Table A1: Reference crops per canton: For all cantons the reference crops used as input for the Proximity Analysis are shown. Only crops grown on more than 1 ha in the corresponding region are listed.

Aargau	**Appenzell Ausserrhoden**	**Appenzell Innerrhoden**	**Basel Land**
Apples	Grapes	Maize	Apples
Asparagus	Maize	Wheat	Asparagus
Barley			Barley
Berries nes			Berries nes
Blueberries			Blueberries
Broad beans, horse beans, dry			Broad beans, horse beans, dry
Cabbages and other brassicas			Cabbages and other brassicas
Carrots and turnips			Carrots and turnips
Cauliflowers and broccoli			Cauliflowers and broccoli
Cherries			Cherries
Chicory roots			Currants
Currants			Fruit, fresh nes
Fruit, fresh nes			Grapes
Garlic			Leeks, other alliaceous vegetables
Grapes			Lentils
Hemp tow waste			Lettuce and chicory
Hops			Linseed
Leeks, other alliaceous vegetables			Lupins
Lentils			Maize
Lettuce and chicory			Maize, green
Linseed			Millet
Maize			Mushrooms and truffles
Maize, green			Oats
Millet			Onions, dry
Mushrooms and truffles			Pears
Mustard seed			Peas, dry
Oats			Plums and sloes
Onions, dry			Potatoes
Pears			Pumpkins, squash and gourds
Peas, dry			Rapeseed
Plums and sloes			Raspberries
Potatoes			Rye
Pumpkins, squash and gourds			Sorghum
Rapeseed			Soybeans
Raspberries			Spinach
Rye			Strawberries
Sorghum			String beans
Soybeans			Sugar beet
Spinach			Sunflower seed
Strawberries			Triticale
String beans			Vegetables, fresh nes
Sugar beet			Wheat
Sunflower seed			
Tobacco, unmanufactured			
Triticale			
Vegetables, fresh nes			
Wheat			

Table A1 continued:

Basel Stadt	**Bern**	**Fribourg**	**Geneva**	**Glarus**
Apples	Apples	Apples	Apples	Barley
Barley	Artichokes	Asparagus	Artichokes	Grapes
Cherries	Asparagus	Barley	Asparagus	Maize
Grapes	Barley	Berries nes	Barley	Triticale
Maize	Berries nes	Blueberries	Berries nes	Wheat
Oats	Blueberries	Broad beans, horse beans, dry	Blueberries	
Rapeseed	Broad beans, horse beans, dry	Cabbages and other brassicas	Broad beans, horse beans, dry	
Rye	Buckwheat	Carrots and turnips	Buckwheat	
Soybeans	Cabbages and other brassicas	Cauliflowers and broccoli	Cabbages and other brassicas	
Triticale	Carrots and turnips	Cherries	Carrots and turnips	
Wheat	Cauliflowers and broccoli	Cucumbers and gherkins	Cauliflowers and broccoli	
	Cherries	Currants	Cherries	
	Chicory roots	Garlic	Chillies and peppers, green	
	Currants	Grapes	Currants	
	Fruit, fresh nes	Hemp tow waste	Grapes	
	Garlic	Leeks, other alliaceous vegetables	Hemp tow waste	
	Grapes	Lentils	Leeks, other alliaceous vegetables	
	Hemp tow waste	Lettuce and chicory	Lentils	
	Leeks, other alliaceous vegetables	Linseed	Lettuce and chicory	
	Lentils	Lupins	Linseed	
	Lettuce and chicory	Maize	Lupins	
	Linseed	Maize, green	Maize	
	Lupins	Millet	Maize, green	
	Maize	Mustard seed	Millet	
	Maize, green	Oats	Mushrooms and truffles	
	Millet	Onions, dry	Oats	
	Mushrooms and truffles	Pears	Onions, dry	
	Mustard seed	Peas, dry	Pears	
	Oats	Peas, green	Peas, dry	
	Onions, dry	Potatoes	Potatoes	
	Pears	Pumpkins, squash and gourds	Pumpkins, squash and gourds	
	Peas, dry	Rapeseed	Rapeseed	
	Plums and sloes	Raspberries	Raspberries	
	Poppy seed	Rye	Rye	
	Potatoes	Sorghum	Safflower seed	
	Pumpkins, squash and gourds	Soybeans	Soybeans	
	Rapeseed	Spinach	Spinach	
	Raspberries	Strawberries	Strawberries	
	Rye	String beans	String beans	
	Sorghum	Sugar beet	Sugar beet	
	Soybeans	Sunflower seed	Sunflower seed	
	Spinach	Tobacco, unmanufactured	Triticale	
	Strawberries	Triticale	Vegetables, fresh nes	
	String beans	Vegetables, fresh nes	Wheat	
	Sugar beet	Wheat		
	Sunflower seed			
	Tobacco, unmanufactured			
	Triticale			
	Vegetables, fresh nes			
	Wheat			

Table A1 continued:

Grisons	**Jura**	**Lucerne**	**Neuchâtel**
Apples	Apples	Apples	Apples
Asparagus	Barley	Asparagus	Barley
Barley	Broad beans, horse beans, dry	Barley	Berries nes
Berries nes	Grapes	Berries nes	Blueberries
Blueberries	Lentils	Blueberries	Broad beans, horse beans, dry
Broad beans, horse beans, dry	Linseed	Broad beans, horse beans, dry	Buckwheat
Buckwheat	Maize	Cabbages and other brassicas	Currants
Cabbages and other brassicas	Millet	Carrots and turnips	Grapes
Carrots and turnips	Mustard seed	Cauliflowers and broccoli	Hemp tow waste
Cauliflowers and broccoli	Oats	Cherries	Lentils
Cherries	Peas, dry	Chestnut	Linseed
Chestnut	Potatoes	Currants	Lupins
Chicory roots	Rapeseed	Grapes	Maize
Currants	Rye	Hemp tow waste	Millet
Fruit, fresh nes	Sorghum	Leeks, other alliaceous vegetables	Mustard seed
Garlic	Soybeans	Lentils	Oats
Gooseberries	Sugar beet	Lettuce and chicory	Peas, dry
Grapes	Sunflower seed	Linseed	Potatoes
Hemp tow waste	Tobacco, unmanufactured	Maize	Rapeseed
Lentils	Triticale	Millet	Raspberries
Lettuce and chicory	Wheat	Oats	Rye
Maize		Onions, dry	Sorghum
Millet		Pears	Soybeans
Oats		Peas, dry	Strawberries
Pears		Plums and sloes	Sugar beet
Peas, dry		Potatoes	Sunflower seed
Potatoes		Pumpkins, squash and gourds	Triticale
Rapeseed		Rapeseed	Wheat
Raspberries		Raspberries	
Rye		Rye	
Soybeans		Sorghum	
Spinach		Soybeans	
Strawberries		Spinach	
Sugar beet		Strawberries	
Sunflower seed		String beans	
Triticale		Sugar beet	
Vegetables, fresh nes		Sunflower seed	
Wheat		Tobacco, unmanufactured	
		Triticale	
		Vegetables, fresh nes	
		Wheat	

Table A1 continued:

Nidwalden	**Obwalden**	**Schaffhausen**	**Schwyz**	**Solothurn**
Apples	Grapes	Apples	Apples	Apples
Maize	Maize	Asparagus	Asparagus	Asparagus
Potatoes		Barley	Barley	Barley
		Berries nes	Berries nes	Berries nes
		Blueberries	Blueberries	Blueberries
		Broad beans, horse beans, dry	Cabbages and other brassicas	Broad beans, horse beans, dry
		Buckwheat	Carrots and turnips	Cabbages and other brassicas
		Cabbages and other brassicas	Cherries	Carrots and turnips
		Carrots and turnips	Chestnut	Cauliflowers and broccoli
		Cauliflowers and broccoli	Currants	Cherries
		Cherries	Grapes	Currants
		Chicory roots	Lettuce and chicory	Fruit, fresh nes
		Currants	Linseed	Grapes
		Fruit, fresh nes	Maize	Hemp tow waste
		Gooseberries	Oats	Hops
		Grapes	Onions, dry	Leeks, other alliaceous vegetables
		Hemp tow waste	Potatoes	Lettuce and chicory
		Leeks, other alliaceous vegetables	Pumpkins, squash and gourds	Linseed
		Lettuce and chicory	Rapeseed	Lupins
		Linseed	Raspberries	Maize
		Lupins	Spinach	Maize, green
		Maize	Strawberries	Millet
		Millet	String beans	Mustard seed
		Oats	Sugar beet	Oats
		Onions, dry	Triticale	Onions, dry
		Pears	Vegetables, fresh nes	Pears
		Peas, dry	Wheat	Peas, dry
		Potatoes		Potatoes
		Pumpkins, squash and gourds		Rapeseed
		Rapeseed		Raspberries
		Raspberries		Rye
		Rye		Sorghum
		Sorghum		Soybeans
		Soybeans		Spinach
		Strawberries		Strawberries
		Sugar beet		String beans
		Sunflower seed		Sugar beet
		Triticale		Sunflower seed
		Vegetables, fresh nes		Triticale
		Wheat		Vegetables, fresh nes
				Wheat

Table A1 continued:

St Gallen	**Ticino**	**Thurgau**	**Uri**
Apples	Apples	Apples	Grapes
Asparagus	Asparagus	Asparagus	Maize
Barley	Barley	Barley	
Berries nes	Cabbages and other brassicas	Berries nes	
Blueberries	Carrots and turnips	Blueberries	
Broad beans, horse beans, dry	Cauliflowers and broccoli	Broad beans, horse beans, dry	
Cabbages and other brassicas	Chestnut	Cabbages and other brassicas	
Carrots and turnips	Eggplants (aubergines)	Carrots and turnips	
Cauliflowers and broccoli	Grapes	Cauliflowers and broccoli	
Cherries	Hemp tow waste	Cherries	
Chicory roots	Leeks, other alliaceous vegetables	Chicory roots	
Currants	Lettuce and chicory	Currants	
Fruit, fresh nes	Lupins	Fruit, fresh nes	
Gooseberries	Maize	Garlic	
Grapes	Onions, dry	Gooseberries	
Hemp tow waste	Potatoes	Grapes	
Leeks, other alliaceous vegetables	Pumpkins, squash and gourds	Hemp tow waste	
Lettuce and chicory	Rice, paddy	Hops	
Linseed	Rye	Leeks, other alliaceous vegetables	
Maize	Sorghum	Lettuce and chicory	
Maize, green	Soybeans	Linseed	
Millet	Spinach	Lupins	
Oats	Sunflower seed	Maize	
Onions, dry	Tomatoes	Maize, green	
Pears	Triticale	Millet	
Peas, dry	Vegetables, fresh nes	Mustard seed	
Plums and sloes	Wheat	Oats	
Poppy seed		Onions, dry	
Potatoes		Pears	
Pumpkins, squash and gourds		Peas, dry	
Rapeseed		Peas, green	
Raspberries		Plums and sloes	
Rye		Potatoes	
Soybeans		Pumpkins, squash and gourds	
Spinach		Rapeseed	
Strawberries		Raspberries	
String beans		Rye	
Sugar beet		Sorghum	
Sunflower seed		Soybeans	
Triticale		Spinach	
Vegetables, fresh nes		Strawberries	
Wheat		String beans	
		Sugar beet	
		Sunflower seed	
		Tobacco, unmanufactured	
		Triticale	
		Vegetables, fresh nes	
		Wheat	

Table A1 continued:

Vaud	**Valais**	**Zurich**	**Zug**
Apples	Apples	Apples	Apples
Asparagus	Apricots	Artichokes	Asparagus
Barley	Asparagus	Asparagus	Barley
Berries nes	Barley	Barley	Berries nes
Blueberries	Berries nes	Berries nes	Blueberries
Broad beans, horse beans, dry	Broad beans, horse beans, dry	Blueberries	Broad beans, horse beans, dry
Buckwheat	Cabbages and other brassicas	Broad beans, horse beans, dry	Cabbages and other brassicas
Cabbages and other brassicas	Carrots and turnips	Buckwheat	Carrots and turnips
Carrots and turnips	Cauliflowers and broccoli	Cabbages and other brassicas	Cauliflowers and broccoli
Cauliflowers and broccoli	Cherries	Carrots and turnips	Cherries
Cherries	Chestnut	Cauliflowers and broccoli	Currants
Chestnut	Chicory roots	Cherries	Grapes
Chicory roots	Currants	Chicory roots	Leeks, other alliaceous vegetables
Currants	Grapes	Currants	Lettuce and chicory
Garlic	Hemp tow waste	Fruit, fresh nes	Maize
Grapes	Lettuce and chicory	Garlic	Millet
Hemp tow waste	Linseed	Gooseberries	Oats
Hops	Lupins	Grapes	Onions, dry
Leeks, other alliaceous vegetables	Maize	Hemp tow waste	Pears
Lentils	Millet	Hops	Potatoes
Lettuce and chicory	Oats	Leeks, other alliaceous vegetables	Pumpkins, squash and gourds
Linseed	Onions, dry	Lentils	Rapeseed
Lupins	Pears	Lettuce and chicory	Raspberries
Maize	Peas, dry	Linseed	Sorghum
Maize, green	Plums and sloes	Lupins	Soybeans
Millet	Potatoes	Maize	Spinach
Mushrooms and truffles	Pumpkins, squash and gourds	Maize, green	Strawberries
Mustard seed	Rapeseed	Millet	String beans
Oats	Raspberries	Mustard seed	Sugar beet
Onions, dry	Rye	Oats	Triticale
Pears	Sorghum	Onions, dry	Vegetables, fresh nes
Peas, dry	Soybeans	Pears	Wheat
Peas, green	Strawberries	Peas, dry	
Plums and sloes	String beans	Peas, green	
Potatoes	Sugar beet	Plums and sloes	
Pumpkins, squash and gourds	Sunflower seed	Potatoes	
Rapeseed	Triticale	Pumpkins, squash and gourds	
Raspberries	Vegetables, fresh nes	Rapeseed	
Roots and tubers, nes	Wheat	Raspberries	
Rye		Rye	
Sorghum		Sorghum	
Soybeans		Soybeans	
Spinach		Spinach	
Strawberries		Strawberries	
String beans		String beans	
Sugar beet		Sugar beet	
Sunflower seed		Sunflower seed	
Tobacco, unmanufactured		Tobacco, unmanufactured	
Tomatoes		Triticale	
Triticale		Vegetables, fresh nes	
Vegetables, fresh nes		Wheat	
Wheat			

Table A2: Reference crops per supracantonal region: For all supracantonal regions the reference crops used as input for the Proximity Analysis are shown. Only crops grown on more than 1 ha in the corresponding region are listed.

Mittelland	**Eastern Switzerland**	**Western Switzerland**	**Central Switzerland**
Apples	Apples	Apples	Apples
Artichokes	Asparagus	Artichokes	Asparagus
Asparagus	Barley	Asparagus	Barley
Barley	Berries nes	Barley	Berries nes
Berries nes	Blueberries	Berries nes	Blueberries
Blueberries	Broad beans, horse beans, dry	Blueberries	Broad beans, horse beans, dry
Broad beans, horse beans, dry	Buckwheat	Broad beans, horse beans, dry	Cabbages and other brassicas
Buckwheat	Cabbages and other brassicas	Buckwheat	Carrots and turnips
Cabbages and other brassicas	Carrots and turnips	Cabbages and other brassicas	Cauliflowers and broccoli
Carrots and turnips	Cauliflowers and broccoli	Carrots and turnips	Cherries
Cauliflowers and broccoli	Cherries	Cauliflowers and broccoli	Chestnut
Cherries	Chestnut	Cherries	Currants
Chicory roots	Chicory roots	Chestnut	Grapes
Cucumbers and gherkins	Currants	Chicory roots	Hemp tow waste
Currants	Fruit, fresh nes	Chillies and peppers, green	Leeks, other alliaceous vegetables
Fruit, fresh nes	Garlic	Currants	Lentils
Garlic	Gooseberries	Garlic	Lettuce and chicory
Grapes	Grapes	Grapes	Linseed
Hemp tow waste	Hemp tow waste	Hemp tow waste	Maize
Hops	Hops	Hops	Millet
Leeks, other alliaceous vegetables	Leeks, other alliaceous vegetables	Leeks, other alliaceous vegetables	Mushrooms and truffles
Lentils	Lentils	Lentils	Oats
Lettuce and chicory	Lettuce and chicory	Lettuce and chicory	Onions, dry
Linseed	Linseed	Linseed	Pears
Lupins	Lupins	Lupins	Peas, dry
Maize	Maize	Maize	Plums and sloes
Maize, green	Maize, green	Maize, green	Potatoes
Millet	Millet	Millet	Pumpkins, squash and gourds
Mushrooms and truffles	Mushrooms and truffles	Mushrooms and truffles	Rapeseed
Mustard seed	Mustard seed	Mustard seed	Raspberries
Oats	Oats	Oats	Rye
Onions, dry	Onions, dry	Onions, dry	Sorghum
Pears	Pears	Pears	Soybeans
Peas, dry	Peas, dry	Peas, dry	Spinach
Peas, green	Peas, green	Peas, green	Strawberries
Plums and sloes	Plums and sloes	Plums and sloes	String beans
Poppy seed	Poppy seed	Potatoes	Sugar beet
Potatoes	Potatoes	Pumpkins, squash and gourds	Sunflower seed
Pumpkins, squash and gourds	Pumpkins, squash and gourds	Rapeseed	Tobacco, unmanufactured
Rapeseed	Rapeseed	Raspberries	Triticale
Raspberries	Raspberries	Roots and tubers, nes	Vegetables, fresh nes
Rye	Rye	Rye	Wheat
Safflower seed	Sorghum	Safflower seed	
Sorghum	Soybeans	Sorghum	
Soybeans	Spinach	Soybeans	
Spinach	Strawberries	Spinach	
Strawberries	String beans	Strawberries	
String beans	Sugar beet	String beans	
Sugar beet	Sunflower seed	Sugar beet	
Sunflower seed	Tobacco, unmanufactured	Sunflower seed	
Tobacco, unmanufactured	Triticale	Tobacco, unmanufactured	
Tomatoes	Vegetables, fresh nes	Tomatoes	
Triticale	Wheat	Triticale	
Vegetables, fresh nes		Vegetables, fresh nes	
Wheat		Wheat	

Table A3: Reference crops for Switzerland: The reference crops used as input for the Proximity Analysis for whole Switzerland are shown.

Switzerland	
Apples	Millet
Apricots	Mushrooms and truffles
Artichokes	Mustard seed
Asparagus	Oats
Barley	Onions, dry
Berries nes	Peaches and nectarines
Blueberries	Pears
Broad beans, horse beans, dry	Peas, dry
Buckwheat	Peas, green
Cabbages and other brassicas	Plums and sloes
Carrots and turnips	Poppy seed
Cauliflowers and broccoli	Potatoes
Cherries	Pumpkins, squash and gourds
Chestnut	Quinces
Chicory roots	Rapeseed
Chillies and peppers, green	Raspberries
Cucumbers and gherkins	Rice, paddy
Currants	Roots and tubers, nes
Eggplants (aubergines)	Rye
Fruit, fresh nes	Safflower seed
Garlic	Sorghum
Gooseberries	Soybeans
Grapes	Spinach
Hemp tow waste	Strawberries
Hops	String beans
Kiwi fruit	Sugar beet
Leeks, other alliaceous vegetables	Sunflower seed
Lentils	Tobacco, unmanufactured
Lettuce and chicory	Tomatoes
Linseed	Triticale
Lupins	Vegetables, fresh nes
Maize	Walnuts, with shell
Maize, green	Wheat
Melons, other (inc.cantaloupes)	

Table A4: Exemplary results of the Proximity Analysis for Jura and Zurich with and without applying a limit to GPV. All Swiss reference crops were excluded.

Ranking	Jura	Jura Limited	Zurich	Zurich Limited
1	Beans, dry	Beans, dry	Beans, dry	Beans, dry
2	Beans, green	Watermelons	Beans, green	Watermelons
3	Watermelons	Beans, green	Watermelons	Beans, green
4	Pulses, nes	Oranges	Oranges	Oranges
5	Oranges	Pulses, nes	Pulses, nes	Pulses, nes
6	Groundnuts, with shell	Lemons and limes	Lemons and limes	Lemons and limes
7	Lemons and limes	Groundnuts, with shell	Groundnuts, with shell	Groundnuts, with shell
8	Cotton lint	Bananas	Vegetables, leguminous nes	Tangerines, mandarins, clementines, satsumas
9	Seed cotton	Tangerines, mandarins, clementines, satsumas	Tangerines, mandarins, clementines, satsumas	Bananas
10	Cottonseed	Seed cotton	Bananas	Sweet potatoes
11	Tangerines, mandarins, clementines, satsumas	Cotton lint	Cotton lint	Vegetables, leguminous nes
12	Bananas	Sweet potatoes	Seed cotton	Grapefruit (inc. pomelos)
13	Vegetables, leguminous nes	Chick peas	Cottonseed	Seed cotton
14	Nuts, nes	Grapefruit (inc. pomelos)	Nuts, nes	Cotton lint
15	Chick peas	Cottonseed	Chick peas	Chick peas
16	Sweet potatoes	Vegetables, leguminous nes	Sweet potatoes	Sugar cane
17	Figs	Sugar cane	Grapefruit (inc. pomelos)	Cottonseed
18	Grapefruit (inc. pomelos)	Chillies and peppers, dry	Figs	Chillies and peppers, dry
19	Sugar cane	Nuts, nes	Sugar cane	Figs
20	Chillies and peppers, dry	Figs	Fruit, citrus nes	Nuts, nes
21	Mangoes, mangosteens, guavas	Mangoes, mangosteens, guavas	Mangoes, mangosteens, guavas	Mangoes, mangosteens, guavas
22	Almonds, with shell	Onions, shallots, green	Chillies and peppers, dry	Fruit, citrus nes
23	Fruit, citrus nes	Fruit, citrus nes	Almonds, with shell	Onions, shallots, green
24	Cereals, nes	Cereals, nes	Onions, shallots, green	Almonds, with shell
25	Sesame seed	Almonds, with shell	Cereals, nes	Avocados
26	Onions, shallots, green	Sesame seed	Vetches	Cereals, nes
27	Vetches	Pineapples	Avocados	Pineapples
28	Spices, nes	Avocados	Sesame seed	Spices, nes
29	Papayas	Spices, nes	Cherries, sour	Cherries, sour
30	Cherries, sour	Cherries, sour	Spices, nes	Olives
31	Avocados	Olives	Papayas	Sesame seed
32	Pineapples	Papayas	Pineapples	Papayas
33	Anise, badian, fennel, coriander	Oilseeds nes	Olives	Oilseeds nes
34	Olives	Cassava	Anise, badian, fennel, coriander	Cassava
35	Oilseeds nes	Anise, badian, fennel, coriander	Oilseeds nes	Anise, badian, fennel, coriander
36	Cassava	Coffee, green	Cassava	Vetches
37	Hazelnuts, with shell	Tea	Hazelnuts, with shell	Coffee, green
38	Tea	Vetches	Tea	Tea
39	Coffee, green	Fruit, stone nes	Coffee, green	Fruit, stone nes
40	Flax fibre and tow	Coconuts	Flax fibre and tow	Coconuts
41	Dates	Hazelnuts, with shell	Fruit, stone nes	Grain, mixed
42	Fruit, stone nes	Dates	Coconuts	Hazelnuts, with shell
43	Coconuts	Grain, mixed	Dates	Dates
44	Grain, mixed	Fruit, tropical fresh nes	Grain, mixed	Fruit, tropical fresh nes
45	Pepper (piper spp.)	Ginger	Ginger	Ginger
46	Fruit, tropical fresh nes	Pepper (piper spp.)	Pepper (piper spp.)	Okra
47	Ginger	Okra	Okra	Pepper (piper spp.)
48	Castor oil seed	Oil, palm	Fruit, tropical fresh nes	Persimmons
49	Okra	Flax fibre and tow	Persimmons	Flax fibre and tow
50	Persimmons	Persimmons	Castor oil seed	Oil, palm
51	Pistachios	Palm kernels	Pistachios	Oil palm fruit
52	Oil, palm	Oil palm fruit	Oil, palm	Palm kernels
53	Palm kernels	Pistachios	Cocoa, beans	Cocoa, beans
54	Oil palm fruit	Cocoa, beans	Palm kernels	Taro (cocoyam)
55	Cocoa, beans	Cow peas, dry	Oil palm fruit	Pistachios

Table A4 continued:

56	Cow peas, dry	Taro (cocoyam)	Taro (cocoyam)	Cow peas, dry
57	Rubber, natural	Castor oil seed	Cow peas, dry	Cashew nuts, with shell
58	Taro (cocoyam)	Cashew nuts, with shell	Carobs	Rubber, natural
59	Carobs	Rubber, natural	Yams	Castor oil seed
60	Cashew nuts, with shell	Yams	Rubber, natural	Yams
61	Yams	Carobs	Cashew nuts, with shell	Carobs
62	Plantains and others	Plantains and others	Plantains and others	Plantains and others
63	Sisal	Bastfibres, other	Sisal	Sisal
64	Jute	Sisal	Jute	Bastfibres, other
65	Canary seed	Fibre crops nes	Canary seed	Fibre crops nes
66	Fibre crops nes	Jute	Fibre crops nes	Jute
67	Bastfibres, other	Canary seed	Bastfibres, other	Canary seed
68	Pigeon peas	Pigeon peas	Pigeon peas	Pigeon peas
69	Melonseed	Melonseed	Melonseed	Cranberries
70	Vanilla	Cranberries	Nutmeg, mace and cardamoms	Melonseed
71	Nutmeg, mace and cardamoms	Vanilla	Vanilla	Vanilla
72	Cranberries	Tung nuts	Cranberries	Nutmeg, mace and cardamoms
73	Tung nuts	Hempseed	Tung nuts	Hempseed
74	Hempseed	Areca nuts	Areca nuts	Areca nuts
75	Areca nuts	Nutmeg, mace and cardamoms	Hempseed	Tung nuts
76	Cloves	Cloves	Cloves	Cloves
77	Ramie	Cinnamon (canella)	Yautia (cocoyam)	Cinnamon (canella)
78	Cinnamon (canella)	Pyrethrum, dried	Cinnamon (canella)	Yautia (cocoyam)
79	Yautia (cocoyam)	Brazil nuts, with shell	Ramie	Pyrethrum, dried
80	Pyrethrum, dried	Maté	Pyrethrum, dried	Agave fibres nes
81	Peppermint	Ramie	Peppermint	Brazil nuts, with shell
82	Brazil nuts, with shell	Yautia (cocoyam)	Agave fibres nes	Quinoa
83	Maté	Agave fibres nes	Brazil nuts, with shell	Ramie
84	Quinoa	Quinoa	Quinoa	Peppermint
85	Agave fibres nes	Peppermint	Maté	Maté
86	Fonio	Fonio	Manila fibre (abaca)	Manila fibre (abaca)
87	Manila fibre (abaca)	Karite nuts (sheanuts)	Fonio	Fonio
88	Karite nuts (sheanuts)	Manila fibre (abaca)	Karite nuts (sheanuts)	Karite nuts (sheanuts)
89	Cashewapple	Cashewapple	Gums, natural	Fruit, pome nes
90	Gums, natural	Fruit, pome nes	Fruit, pome nes	Gums, natural
91	Fruit, pome nes	Gums, natural	Sugar crops, nes	Sugar crops, nes
92	Kola nuts	Kola nuts	Cashewapple	Cashewapple
93	Sugar crops, nes	Sugar crops, nes	Kola nuts	Kola nuts
94	Bambara beans	Bambara beans	Bambara beans	Bambara beans
95	Kapok fruit	Kapok fruit	Kapok fruit	Kapok fruit

Table A5: Complete proximity list for Switzerland. Positions 1 to 35 correspond to positions 1 to 30 in table 1 of the manuscript, except that in table 1 the items “Vegetables leguminous nes”, “Cotton lint”, “Seed cotton”, “Cottonseed” and “Vetches” were excluded because they do not represent food crops. No limit was applied to GPV. All Swiss reference crops were excluded.

Switzerland			
Ranking	**Crop**	**Ranking**	**Crop**
1	Beans, dry	49	Persimmons
2	Beans, green	50	Pistachios
3	Watermelons	51	Castor oil seed
4	Oranges	52	Cocoa, beans
5	Pulses, nes	53	Oil, palm
6	Lemons and limes	54	Palm kernels
7	Groundnuts, with shell	55	Oil palm fruit
8	Bananas	56	Taro (cocoyam)
9	Vegetables, leguminous nes	57	Cow peas, dry
10	Tangerines, mandarins, clementines, satsumas	58	Yams
11	Sweet potatoes	59	Carobs
12	Cotton lint	60	Rubber, natural
13	Seed cotton	61	Cashew nuts, with shell
14	Cottonseed	62	Plantains and others
15	Nuts, nes	63	Sisal
16	Chick peas	64	Jute
17	Grapefruit (inc. pomelos)	65	Canary seed
18	Figs	66	Fibre crops nes
19	Sugar cane	67	Bastfibres, other
20	Mangoes, mangosteens, guavas	68	Pigeon peas
21	Fruit, citrus nes	69	Nutmeg, mace and cardamoms
22	Chillies and peppers, dry	70	Melonseed
23	Almonds, with shell	71	Vanilla
24	Onions, shallots, green	72	Cranberries
25	Cereals, nes	73	Areca nuts
26	Avocados	74	Tung nuts
27	Pineapples	75	Hempseed
28	Papayas	76	Cloves
29	Sesame seed	77	Yautia (cocoyam)
30	Vetches	78	Cinnamon (canella)
31	Spices, nes	79	Ramie
32	Cherries, sour	80	Pyrethrum, dried
33	Olives	81	Peppermint
34	Anise, badian, fennel, coriander	82	Agave fibres nes
35	Cassava	83	Brazil nuts, with shell
36	Oilseeds nes	84	Quinoa
37	Hazelnuts, with shell	85	Manila fibre (abaca)
38	Coffee, green	86	Maté
39	Tea	87	Fonio
40	Coconuts	88	Karite nuts (sheanuts)
41	Flax fibre and tow	89	Fruit, pome nes
42	Fruit, stone nes	90	Gums, natural
43	Dates	91	Kola nuts
44	Grain, mixed	92	Sugar crops, nes
45	Ginger	93	Cashewapple
46	Okra	94	Bambara beans
47	Pepper (piper spp.)	95	Kapok fruit
48	Fruit, tropical fresh nes		

Appendix 2: EcoCrop Alternative Analysis – Additional Material

A2.1 Additional Materials and Methods

Table A6 contains all reference crops for which the Alternative Analysis was performed. Only reference crops for which the used version of EcoCrop contains a data sheet are shown. The following reference crops are not contained in EcoCrop and therefore had to be excluded from the analysis:

- *Beta vulgaris subsp. vulgaris*
- *Brassica oleracea var. botrytis*
- *Brassica oleracea var. sabellica*
- *Brassica rapa subsp. pekinensis*
- *Camelina sativa*
- *Cichorium intybus var. foliosum f. cylindricum*
- *Cucumis metuliferus*
- *Cucurbita pepo var. giromontiina*
- *Triticosecale rimpaui*
- *Lactuca sativa*
- *Lepidium sativum*
- *Oryza sativa*
- *Pisum sativum var. saccharatum*
- *Raphanus sativus var. sativus*
- *Scorzonera hispanica*
- *Triticum monococcum*
- *Valerianella locusta*

A2.2 Additional Results and Discussion

The complete results of the analysis can be found in table A7. The frequency in table A7 indicates how many times the crop was identified as an alternative. Crops with a frequency below 10 were excluded. While it is impossible to scientifically determine a cut-off value for the frequency a lower frequency theoretically indicates lower suitability for Swiss agriculture. For some reference crops EcoCrop delivered very long lists of alternatives, in rare cases containing up to 800 crops. Clearly, it has to be assumed that such a long list of alternatives for one single reference crop is not very specific. Therefore, 10 was chosen as cut-off value for the frequency to exclude crops mentioned only on unspecific alternative lists. The majority of crops identified were non-food crops (written in black in table A7). They represent mainly tree and feed crop species that are not of interest for the present study. The crops written in green font in table A7 represent reference crops and the ones written in red are newly identified food crops. It is interesting to note that only a very small amount of reference crops appeared

with a high ranking. Rather they appear somewhere in the middle of the list with a frequency between 12 and 18. This could indicate that the Alternative Analysis could identify more new crops than described in the manuscript. However, it remains to be tested whether new crops with a frequency below 20 (which are therefore not included in the manuscript) are indeed suited for Swiss agriculture.

Table A6: List of reference crops used for the EcoCrop Alternative Analysis

Actinidia deliciosa	Lactuca sativa var. capitata
Allium ampeloprasum	Lens culinaris
Allium cepa	Linum usitatissimum
Allium sativum	Lupinus albus
Allium schoenoprasum	Lupinus angustifolius
Allium ursinum	Malus domestica
Apium graveolens var. dulce	Nicotiana tabacum
Apium graveolens var. rapaceum	Panicum miliaceum
Armoracia rusticana	Papaver somniferum
Asparagus officinalis	Pastinaca sativa
Avena sativa	Petroselinum crispum
Beta vulgaris subsp. Saccharifera	Phaseolus vulgaris
Brassica napus	Pisum sativum
Brassica oleracea var. capitata	Portulaca oleracea
Brassica oleracea var. gemmifera	Prunus armeniaca
Brassica oleracea var. gongyloides	Prunus avium
Brassica oleracea var. italica	Prunus domestica
Brassica rapa Pak Choi	Prunus persica
Cannabis sativa subsp. indica	Pyrus communis
Capsicum annuum	Raphanus sativus
Carthamus tinctorius	Rheum rhaponticum
Castanea sativa	Ribes rubrum
Cichorium intybus	Ribes uva-crispa
Cucumis melo	Rubus fruticosus
Cucumis sativus	Rubus idaeus
Cucurbita maxima	Sambucus nigra
Cucurbita pepo	Secale cereale
Cydonia oblonga	Sinapis alba
Cynara cardunculus	Solanum lycopersicum
Cynara scolymus	Solanum melongena
Daucus carota	Solanum muricatum
Eruca vesicaria	Solanum tuberosum
Fagopyrum esculentum	Sorghum bicolor
Foeniculum vulgare	Spinacia oleracea
Fragaria x ananassa	Triticum aestivum
Glycine max	Triticum dicoccon
Helianthus annuus	Triticum spelta
Helianthus tuberosus	Vaccinium myrtillus
Hordeum vulgare	Vicia faba
Humulus lupulus	Vitis vinifera
Juglans regia	Zea mays subsp. mays

Table A7: Complete results of the EcoCrop Alternative Analysis. Shown are all alternatives that were identified at least 10 times, regardless of their use. Crops written in black are not food crops and are therefore not of interest for the present study. Crops written in green are Swiss reference crops and crops written in red are new crops. Those that were found 20 times or more in the analysis are also contained in table 1 of the manuscript.

crop	Frequency	description
Beta vulgaris	65	beet
Apium graveolens var. rapaceum	63	celeriac
Lotus corniculatus	61	feed crop
Vicia monantha	61	feed crop
Vicia sativa subsp. sativa	61	feed crop
Trifolium resupinatum	60	feed crop
Bromus carinatus	58	feed crop
Lespedeza stipulacea	58	feed crop
Setaria italica	58	foxtail millet
Vicia sativa subsp. nigra	58	feed crop
Poa fendleriana	56	feed crop
Trifolium medium	55	feed crop
Alopecurus arundinaceus	50	feed crop
Oryzopsis miliacea	50	feed crop
Rumex obtusifolius	50	weed
Sehima nervosum	49	feed crop
Themeda triandra	49	feed crop
Brassica napus var. napobrassica	48	rutabaga
Lespedeza cuneata	47	feed crop
Poa annua	47	feed crop
Vicia narbonensis	47	feed crop
Arrhenatherum elatius	46	feed crop
Bromus inermis	46	feed crop
Panicum antidotale	46	feed crop
Sapium sebiferum	46	tree
Brassica nigra	45	black mustard
Festuca rubra var. rubra	44	feed crop
Setaria sphacelata 'Nandi'	44	feed crop
Cinnamomum camphora	43	tree
Setaria sphacelata 'Narok'	40	feed crop
Astragalus cicer	39	feed crop
Medicago lupulina	39	feed crop
Trifolium hirtum	38	feed crop
Festuca rubra var. commutata	37	feed crop
Lupinus angustifolius	37	blue lupin
Trifolium fragiferum	37	feed crop
Arundinaria pusilla	35	bamboo
Chrysanthemum coronarium var. coronarium	35	feed crop
Medicago arabica	35	feed crop
Taraxacum officinale	35	feed crop
Quercus dilatata	34	tree
Ailanthus altissima	33	tree
Araucaria bidwillii	33	tree
Carissa carandas	33	karanda
Lespedeza striata	33	feed crop
Acacia mearnsii	32	tree
Ixophorus unisetus	32	feed crop
Trifolium repens	32	feed crop
Canna edulis	31	ornamental
Crotalaria brevides var. brevides	31	feed crop
Eugenia uniflora	31	Surinam cherry
Olea cuspidata	31	tree
Acehmea magdalenae	30	fiber crop
Alnus nepalensis	29	tree
Raphanus sativus	29	radish
Sansevieria guineensis	29	fiber crop
Casuarina luehmannii	27	tree
Indigofera spicata	27	colorant
Psidium cattleianum	27	strawberry guava

Table A7 continued:

crop	Frequency	description
Quercus incana	27	tree
Panicum maximum var. tr.	26	feed crop
Phormium tenax	26	fiber crop
Telfairia pedata	26	oyster nut
Derris malaccensis	25	medicinal
Dimocarpus longan var. long	25	longan
Physalis peruviana	25	cape gooseberry
Solanum ferox	25	hairy-fruited eggplant
Yucca elephantipes	25	tree
Acacia melanoxylon	24	tree
Anogeissus pendula	24	tree
Cryptomeria japonica	24	tree
Boehmeria nivea	23	fiber crop
Carissa edulis	23	climbing num-num
Crotalaria lanceolata	23	feed crop
Elymus glaucus	23	feed crop
Vigna parkeri	23	feed crop
Fibraurea tinctoria	22	colorant
Nothofagus cunninghamii	22	tree
Acacia decurrens var. decurrens	21	tree
Crotalaria pallida	21	shrub
Telfairia occidentalis	21	fluted pumpkin
Centrosema macrocarpum	20	feed crop
Dioscorea cayenensis	20	yellow yam
Flemingia macrophylla	20	colorant
Melilotus suaveolens	20	feed crop
Pinus durangensis	20	tree
Sechium edule	20	chayote
Trifolium incarnatum	20	feed crop
Trifolium vesiculosum	20	feed crop
Vicia villosa subsp. villosa	20	feed crop
Baphia nitida	19	tree
Benincasa hispida	19	wax gourd
Bromus unioloides	19	feed crop
Carum carvi	19	caraway
Cupressus lusitanica	19	tree
Desmodium gyroides	19	feed crop
Desmodium sandwicense	19	feed crop
Diospyros virginiana	19	American persimmon
Elymus condensatus	19	feed crop
Medicago scutellata	19	feed crop
Melilotus indica	19	feed crop
Myrtus communis	19	shrub
Ornithopus roseus	19	feed crop
Phalaris coerulescens	19	feed crop
Themeda australis	19	feed crop
Vicia benghalensis	19	feed crop
Vicia villosa subsp. dasy.	19	feed crop
Acacia silvestris	18	tree
Alnus japonica	18	tree
Brassica napus	18	rapeseed
Oxalis tuberosa	18	oca
Pinus douglasiana	18	tree
Vicia ervilia	18	feed crop
Vicia faba	18	broad bean
Acacia salicina	17	tree
Aleurites fordii	17	tree
Annona cherimola	17	cherimoya
Caryota urens	17	tree
Cleistogenes chinensis	17	feed crop
Coronilla varia	17	feed crop
Digitalis purpurea	17	ornamental
Hedysarum coronarium	17	feed crop
Malus sylvestris	17	tree
Melilotus officinalis	17	feed crop
Melinis minutiflora	17	feed crop
Pastinaca sativa	17	parsnip

Table A7 continued:

crop	Frequency	description
Pinus psedostrobus var. oaxac.	17	tree
Rubus occidentalis	17	black raspberry
Rubus occidentalis x idaeus	17	purpel raspberry
Sambucus cerulea	17	blue elderberry
Trachyspermum ammi	17	ajowan
Triticum compactum	17	club wheat
Agropyron intermedium	16	feed crop
Beta vulgaris var. crassa	16	feed crop
Bothriochloa insculpta	16	feed crop
Bouteloua curtipendula	16	feed crop
Cenchrus pennisetiformis	16	feed crop
Cydonia oblonga	16	quince
Deyeuxia angustifolia	16	feed crop
Levisticum officinale	16	lovage
Melia azedarach	16	tree
Nigella sativa	16	black cumin
Pinus oocarpa var. ochoterenai	16	tree
Ribes nigrum	16	black currant
Ribes sativum	16	red currant
Sambucus canadensis	16	American elderberry
Trifolium pratense	16	feed crop
Trigonella foenum-graecum	16	fenugreek
Acacia dealbata	15	tree
Agave sisalana	15	fiber crop
Apium graveolens var. dulce	15	celery
Brassica oleracea var. gemmifera	15	brussels sprout
Cannabis sativa subsp. indica	15	hemp
Catha edulis	15	tree
Eruca sativa	15	garden rocket
Eucalyptus cloeziana	15	tree
Fagopyrum emarginatum	15	buckwheat
Fagopyrum esculentum	15	buckwheat
Hordeum brevisubulatum	15	feed crop
Lolium rigidum	15	feed crop
Mentha spicata var. crispa	15	spearmint
Orbignya cohume	15	tree
Papaver somniferum	15	poppy
Rumex crispus	15	feed crop
Solanum muricatum	15	pepino
Stachys affinis	15	Chinese artichoke
Urochloa oligotricha	15	feed crop
Acacia neriifolia	14	tree
Acer saccharum	14	tree
Agropyron trachycaulum	14	feed crop
Brassica rapa Pak Choi	14	bok choi
Bromus marginatus	14	feed crop
Chenopodium pallidicaule	14	canihua
Eucalyptus calophylla	14	tree
Eucalyptus exserta	14	tree
Eucalyptus patens	14	tree
Eucalyptus radiata subsp. rad	14	tree
Ficus carica	14	common fig
Lotus tenuis	14	feed crop
Mentha arvensis var. piperascens	14	corn mint
Onobrychis viciifolia	14	feed crop
Opuntia ficus-indica	14	cactus pear
Persea americana subsp. Guatemalan	14	avocado
Persea americana subsp. Mexican	14	avocado
Phalaris canariensis	14	feed crop
Physalis philadelphica	14	tomatillo
Pinus ponderosa	14	tree
Quercus ilex	14	tree
Ribes hirtellum	14	American gooseberry
Ribes rubrum	14	red currant
Rubus idaeus	14	red raspberry
Salix babylonica var. sacramenta	14	tree
Sanguisorba minor	14	feed crop
Trifolium tomentosum	14	feed crop

Table A7 continued:

crop	Frequency	description
Acacia falciformis	13	tree
Agropyron repens	13	feed crop
Annona squamosa	13	sugar-apple
Bouteloua gracilis	13	feed crop
Casuarina fraseriana	13	tree
Chenopodium album subsp. album	13	white goosefoot
Chenopodium quinoa	13	quinoa
Colchicum autumnale	13	toxic
Diospyros digyna	13	black sapot
Eucalyptus cornuta	13	tree
Eucalyptus guilfoylei	13	tree
Eucalyptus jacksonii	13	tree
Eucalyptus marginata	13	tree
Festuca idahoensis	13	feed crop
Fragaria x ananassa	13	garden strawberry
Livistona australis	13	tree
Lupinus mutabilis	13	South American lupin
Medicago truncatula	13	feed crop
Melia azedarach var. austral.	13	tree
Mirabillis expansa	13	mauka
Pinus rudis	13	tree
Pinus sylvestris	13	tree
Polymnia sonchifolia	13	yacon
Prunus cerasus	13	sour cherry
Sesbania cannabia	13	weed
Sesbania exaltata	13	weed
Solanum oleraceum	13	toxic
Spinacia oleracea	13	spinach
Taxodium distichum	13	tree
Trifolium alexandrinum	13	feed crop
Artemisia abrotanum	12	shrub
Bromus tomentellus	12	feed crop
Carica pubescens	12	mountain papaya
Chenopodium ambrosioides	12	feed crop
Cupressus macrocarpa	12	tree
Cynodon nlemfuensis	12	feed crop
Cynodon plectostachyus	12	feed crop
Dioscorea composita	12	medicinal
Erythrophleum chlorostahys	12	tree
Eucalyptus albens	12	tree
Eucalyptus bosistoana	12	tree
Eucalyptus elata	12	tree
Eucalyptus leucoxylon	12	tree
Eucalyptus muelleriana	12	tree
Eucalyptus radiata subsp. rob	12	tree
Humulus lupulus	12	hops
Lupinus albus	12	white lupin
Phaseolus lunatus	12	lima bean
Pinus radiata	12	tree
Prunus mume	12	Japanese apricot
Psathyrostachys juncea	12	feed crop
Raphanus sativus (R.R.)	12	rat-tailed radish
Robinia pseudoacacia	12	tree
Sauropus androgynus	12	star gooseberry
Solanum nigrum	12	toxic
Vaccinium macrocarpon	12	cranberry
Zoysia matrella	12	feed crop
Acacia bidwillii	11	tree
Acacia saligna	11	tree
Agropyron tauri	11	feed crop
Avena sterilis	11	feed crop
Bothriochloa pertusa	11	feed crop
Cassia occidentalis	11	shrub
Chrysanthemum coccineum	11	medicinal
Eucalyptus polyanthemos	11	tree
Feijoa sellowiana	11	feijoa, pineapple guava
Ficus macrophylla	11	tree
Fragaria chiloensis	11	Chilean strawberry

Table A7 continued:

crop	Frequency	description
Fragaria virginiana	11	Virginia strawberry
Hardwickia binata	11	tree
Koeleria cristata	11	feed crop
Lansium domesticum	11	langsat
Mallotus philippensis	11	tree
Mimosa pudica	11	feed crop
Poa pratensis	11	feed crop
Psidium friedrichsthalianum	11	Costa Rican guava
Sesbania bispinosa	11	feed crop
Trifolium ambiguum	11	feed crop
Trifolium hybridum	11	feed crop
Trifolium nigrescens	11	feed crop
Trifolium pilulare	11	feed crop
Urochloa mosambicensis	11	feed crop
Achnatherum splendens	10	feed crop
Acmena smithii	10	tree
Adhatoda vasica	10	shrub
Agropyron elongatum	10	feed crop
Albizia stipulata	10	tree
Arracacia xanthorrhiza	10	Peruvian carrot
Atherosperma moschatum	10	tree
Brachiaria decumbens	10	feed crop
Brachiaria humidicola	10	feed crop
Callitris macleayana	10	tree
Cassia brewsteri	10	tree
Casuarina stricta	10	tree
Clitoria ternatea	10	feed crop
Cupressus arizonica	10	tree
Dalbergia latifolia	10	tree
Digitaria exilis	10	white fonio
Echinochloa colona	10	feed crop
Eucalyptus microcorys	10	tree
Eucalyptus pellita	10	tree
Eucryphia lucida	10	tree
Festuca arundinacea	10	feed crop
Hippophae rhamnoides	10	sea buckthorn
Hyparrhenia hirta	10	feed crop
Lupinus cosentinii	10	sandplain lupin
Mentha rotundifolia	10	applemint
Nepeta cataria	10	medicinal
Passiflora quadrangularis	10	giant granadilla
Persea americana subsp. West Indian	10	avocado
Pinus michoacana var. cornuta	10	tree
Pinus montezumae	10	tree
Schizomeria ovata	10	tree
Spartium junceum	10	fiber crop
Syncarpia glomulifera	10	tree
Syzygium malaccense	10	pommerac
Trichosanthes cucumerina	10	snake gourd
Tristania conferta	10	tree

Appendix 3: Stakeholder Interviews – Additional Material

A3.1 Interview Guideline

The interviews were conducted in German. Therefore, the interview guideline was prepared in German. The parts labeled in yellow were adjusted to fit the company or organization the stakeholder is working for. The different versions are labeled a) – e) and refer to:

a) Stakeholders from research organizations
b) Stakeholders from the policy making environment
c) Stakeholders from breeding and seed companies
d) Farmers
e) Stakeholders from processing and distribution

1. Zum Einstieg, ganz generell: Welche Kriterien muss Ihrer Meinung nach eine neue Kultur (Nischenkultur) erfüllen, um in der Schweiz erfolgreich angebaut zu werden? Sie können gerne die ganze Wertschöpfungskette beachten von der Produktion über Verarbeitung und Vertrieb bis zum Konsum.

2. Wenn Sie sich nun überlegen a) eine neue Kultur ins Forschungsprogram aufzunehmen, b) sich mit einer neuen Kultur zu beschäftigen, c) eine neue Kultur ins Zuchtprogram aufzunehmen, d) eine neue Kultur in Ihrem Betrieb anzubauen, e) ein neues Produkt aus einer Nischenkultur ins Sortiment aufzunehmen, welche Faktoren/Kriterien sind für Sie wichtig?

3. Können Sie ein Beispiel machen für eine Kultur/Produkt, a) welche Sie in den letzten Jahren ins Forschungsprogram aufgenommen haben, b) mit welcher Sie sich kürzlich neu zu beschäftigen begonnen haben, c) für welche Sie in den letzten Jahren neu ein Zuchtprogram etabliert haben, d) welche Sie in den letzten Jahren neu angebaut haben, e) welche Sie in den letzten Jahren neu ins Sortiment aufgenommen haben? Und erläutern, was eine Rolle gespielt hat bei der Entscheidung, damit anzufangen?

4. Habe sich die ursprünglichen Befürchtungen/Hoffnungen bestätigt? Sind neue wichtige Punkte aufgetaucht?

Zusammenfassen: 2-3 allgemeine Kriterien und 2-3 spezifische Kriterien:

5. Könnte man also sagen, dass die Kriterien 1, 2 und 3 Ihrer Meinung nach eine grosse Relevanz haben von einem allgemeinen Standpunkt und die Kriterien A, B und C für Sie im Speziellen? Habe ich etwas Wichtiges vergessen?

6. Sind alle diese Kriterien gleich wichtig oder gibt es eine Hierarchie? Würden Sie eines (oder mehrere) Kriterien als Killer-Kriterium bezeichnen?

Erklärung betreffend das selbstständige Verfassen einer Masterarbeit im Departement Life Sciences und Facility Management

Mit der Abgabe dieser Masterarbeit versichert der/die Studierende, dass er/sie die Arbeit selbständig und ohne fremde Hilfe verfasst hat.

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Bei Verfehlungen aller Art treten Paragraph 39 und Paragraph 40 der Rahmenprüfungsordnung für die Bachelor- und Masterstudiengänge an der Zürcher Hochschule für Angewandte Wissenschaften vom 29. Januar 2008 sowie die Bestimmungen der Disziplinarmassnahmen der Hochschulordnung in Kraft.

Ort, Datum: Unterschrift:

Zürich, 9.1.20 St. Gysi