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MASTER'S THESIS

Towards a more sustainable soybean production in Austria: A socio-ecological review

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Abstract

Soybean is a crop with great potential and continuously growing in popularity. An insight in current research interests in soybean breeding, a broader socio-economic setting, an introduction to the sustainability concept, and current predictions on climate scenarios are provided in this thesis. This combination targets at identifying sustainable pathways for future developments. Since soybean breeding is a long-term process it consequently needs to be foresighted and considerate. Therefore, the aim was to illustrate an outlook for future soybean breeding in Austria by determining targets (agronomy and consumption related) that are consistent with the concept of sustainability and in alignment with current predictions and ongoing debates on future developments. This thesis is based on literature research and complemented by data gathered during ve months of project related work at the Chamber of Agriculture in Upper Austria. The major ndings reveal i) that enhancing diversity and soil health should be of immediate interest when formulating future objectives, ii) the importance of aiming at robust cultivars and iii) the signi cance of encouraging the cultural value of soybean and further promotion of soybean as a foodstu . Meanwhile, careful attention should be directed at continuously improving food safety issues and quality parameters, while encouraging innovative solutions within the sector to avoid bottlenecks in the supply. In summary, the ndings illustrate the necessity of a variety of different, transdisciplinary and in a best case scenario complementing measures that connect stakeholders in order to allow for a signi cant shift towards a sustainable and resilient soybean breeding sector

Kurzfassung

Sojabohnen besitzen gro es Potential und erfreuen sich zunehmender Popularität. Basierend auf dem derzeitigen Forschungsinteresse im Bereich der Sojazüchtung, einer sozio-ökonomischen Einbettung, einer Einführung des Nachhaltigkeitskonzepts und anhand eines kurzen Abrisses von derzeitigen Klimaszenarien, sollen im Rahmen dieser Masterarbeit Möglichkeiten ausgemacht und aufgezeigt werden, um nachhaltige Entwicklungen forcieren zu können. Da es sich bei der Sojazüchtung um einen langfristigen Prozess handelt, ist es sinnvoll, Prognosen über zukünftige Entwicklungen miteinzubeziehen. Der Anspruch der Arbeit besteht daher darin, mögliche Ziele im Bereich der zukünftigen Sojazüchtung für Österreich aufzuzeigen, die kohärent mit dem Konzept der Nachhaltigkeit sowie mit aktuellen Prognosen und Debatten hinsichtlich globaler Entwicklungen (wie beispielsweise dem Klimawandel, oder der Ernährungssicherung) sind. Die Arbeit basiert auf Literaturrecherchen sowie auf Daten, die im Rahmen einer fünf monatigen projektbezogenen Tätigkeit an der Landwirtschaftskammer Oberösterreich gesammelt wurden. Für zukünftige Zielsetzungen wäre es daher äu erst bedeutend, auf folgendes zu fokussieren: i) eine Steigerung der Vielfalt und der Bodengesundheit, ii) Förderung robuster Sorten iii) Verbesserung der Wahrnehmung der Sojabohne als Nahrungsmittel, deren kulturellen Wert, sowie eine Verbesserung der Nahrungsmittelsicherheit und Qualitätsmerkmalen bei gleichzeitiger Förderung innovativer Lösungen zur Vermeidung von Versorgungsengpässen. Es zeigte sich, dass eine Vielzahl an (im besten Fall gut abgestimmten) transdisziplinären Ma nahmen unter Einbindung der Stakeholder notwendig wären, um die österreichische Sojazüchtung nachhaltig und resilient gestalten zu können

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List of Abbreviations

ABA	Abscisic Acid
AMF	Arbuscular Mycorrhizal Fungi
BNF	Biological Nitrogen Fixation
BWSB	Boden.Wasser.Schutz.Beratung
CAP	Common Agricultural Policy
CT	Conventional Tillage
DAS	Spectrum of the developmental stages of soybeans
DDGS	Dried Distillers Grains Solubels
ES	Ecosystem Service
FAO	Food and Agriculture Organization of the United Nations
GAP	Good Agricultural Practice
GMO	Genetically Modi ed Organism
HBN	Haber-Bosch Technique (Nitrogen Source)
HI	Harvest Index
IMF	Integrated Modeling Frameworks
KTI	Kunitz Trypsin Inhibitor
LAI	Leaf Area Index
NT	No-Tillage System
OM	Organic Matter
POM	Particulate Organic Matter
RFOs	Ra nosaccharides/Ra nose Family Oligo Saccharides
SAPs	Structural Adjustment Programmes
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
WTO	World Trade Organization
ÖPUL	Österreichisches Programm für umweltgerechte Landwirtschaft

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1 INTRODUCTION

Developing a new soybean cultivar takes years. Therefore soybean breeding needs to be foresighted and current projections on future developments considered. *Sustainability* has become a true buzzword, however due to its holistic character it is also rather difficult to work with. Nonetheless the concept may offer a roadmap towards solving current and future challenges.

The aim of this thesis is to identify long-term soybean breeding targets (agronomic and consumption related) in Austria until 2050, coherent with the concept of *sustainability* and aligned with current discussions on e.g. enhancing *soil health*, global food systems and *food security*.

1.1 Problem statement

Living in today's reality entails inevitable confrontations with uneasy, complex and highly interlinked challenges, such as climate change, on a regular basis. In attempts to find smart ways to navigate through these upcoming challenges the *sustainability* concept still gains in importance. Similar developments may be observed with respect to the rising recognition of truly needed transdisciplinary research.

As agriculture is significantly influenced by environmental conditions as well as its societal embeddedment, the food producing sector is not exempted from transformations in either sphere but rather considered to be particularly vulnerable instead.

The thesis therefore offers an approach in which aspects rooted in social and agronomic dimensions are considered. Additionally, correlations between both spheres as well as subsequent consequences are outlined. Today's core breeding goals (agronomic and consumption related) serve as a starting point, constituting the basis to discover and understand adjacent topics and how they correlate with the subject of research. Moreover, this approach allows for a broader understanding of the context in which soybean breeding goals are embedded. As practiced in quilting, mosaic-like pieces from different disciplines are brought together, continuously extending the understanding of the vast and complex system we live in.

The initial research questions were I) How could *sustainable* soybean breeding goals (related to agronomy and consumption patterns) look like in Austria in the year 2050? and II) What would qualify them as being *sustainable* and why?

Connecting different disciplines and looking at the topic from various vantage points was a deliberately chosen challenge. However, it was soon to be discovered that the implementation of the sustainability concept would have rested predominantly on the delicate task of finding suitable and meaningful indicators within each discipline discussed. Subsequently, an extensive amount of expertise in each field would have been needed as a prerequisite to enable a smart and educated choice of indicators. In short, appart from calling profound knowledge in each relevant yet inhomogeneous disciplines, this would have meant that results and conclusions which were hoped to be acquired in the course of writing this thesis would have actually been required up front.

Another paradox concerns the transdisciplinary character which is implied and promoted by the sustainability concept (e.g. in respect with the three interlinked pillars, see the following Chapter). Yet, in this particular case, an implementation of the concept would have lead to the already mentioned ostensibly overwhelming task of choosing suitable indicators for every single field relevant to the matter of research. As a consequence, any additional perspective introduced by adhering to a transdisciplinary approach would have been discouraged because holding true scientific rigour would demand even more indicators and further expertise to be included. At least with respect to this thesis and in my personal opinion, this would have led to a rather limiting, seemingly impossible, and consequently unsuitable approach. Hence, persuing this path would not have been viable within scope of this Master's thesis.

Since I was, and still am, convinced of the highly beneficial concept of sustainability and the aim of discovering various perspectives on the topic, I chose to slightly alter the approach. So as to maintain the transdisciplinary character and to be able to embed the topic in a broader context. Therefore, taking into account the reservations and limitations outlined above, the research focus was adjusted accordingly.

Consequently, as already stated in the introduction, the ultimate aim was to identify *long-term* soybean breeding targets (agronomic and consumption related) in Austria until 2050, coherent with the concept of *sustainability* and aligned with current discussions. This allowed for the initial idea to be preserved, while creating sufficient degrees of freedom to explore adjacent topics in all directions in order to obtain a better understanding of complex interactions and the setting itself.

Suggestions expressed in the conclusion are specifically intended for industries, non governmental organizations, policy makers, practitioners and researchers (in alphabetical order) alike. In this sense the thesis is intended as a humble contribution to identify interrelations between social and environmental spheres and their implications, as well as a range of suggestions which would support a relatively gentle transformation towards a more *resilient* soybean breeding sector in Austria until 2050.

1.1.1 Sustainability

In order to target these questions it was initially intended to find a more or less meticulous definition of *sustainability* that would apply to the framework of the two groups of today's soybean breeding goals in Austria (e.g. sustainability in an agricultural setting with one focus on agronomy and a second on consumption related patterns) in order to create reference points. Such detailed definitions would be necessary because - as Báberi (2013, 3) points out - the term sustainability has become a buzzword, which is used inflationary with a vast amount of different (yet often unclear) definitions. Similarly, Popp et al. (2000) mention that *"[...] sustainability, as a concept, is enigmatic. For decades, scholars across disciplines have struggled to uncover its 'true' meaning and the associated directives for resource management ".*

Problematic use of the concept has for example arisen due to its inherent continuously evolving dynamics (Báberi 2013, 3), as well as its holistic nature (Böhringer and Jochem 2007 and Dahl 2012). Furthermore Dahl (2012) points out that the concept of sustainability has also become an ethical challenge, thereby individual actions and choices have shifted into focus in an increasing degree.

Institutions and scientists put a lot of effort into establishing indicators in order to create ways to work with - and measure - such a complex concept. Those indicators would provide features to *"[...] summarise, focus and condense the enormous complexity of our dynamic environment to a manageable amount of meaningful information* (Godfrey and Todd, 2001, as cited in Singh R. R. et al. 2009). Although according to Dahl (2012), interventions and actions based on process-oriented indicators would be harder to define, but more effective than actions based solely on result-oriented indicators.

Up to now a vast amount of sustainability indices were introduced and have continuously gained attention as valuable tools for policy making (Singh R. R. et al. 2009). For instance Böhringer and Jochem (2007) refer to a *Compendium of Sustainable Development Indicator Initiatives* published by Parris and Kates (2003) which lists more than 500 approaches trying to find suitable sets of indicators for sustainability in a time frame collected within the past 20 years. The authors selected eleven indices which in their opinion were the most consistent and meaningful considering a correct normalization, meaningful aggregation of variables and an assured commensurability of input variables in order to be coherent with basic scientific requirements (Böhringer and Jochem 2007). Another review of sustainability assessment methodologies is given e.g. by Singh R. R. et al. (2009).

The roots of the term are situated in the *World Conservation Strategy* of 1980 by the

International Union for Conservation of Nature (IUCN), the United Nations Environment Programme (UNEP) and the World Wide Fund for Nature (WWF) (Moldan et al. 2012). Although the most quoted de nition of *sustainable development* derives from the World Commission on Environment and Development Report (WCED, 1987) with the title *Our Common Future* (that came to be known as the *Brundtland report*) (EPA et al. 2012, 4f. and Moldan et al. 2012), and states that [...] *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (WCED 1987, 8, also cited in Singh R. R. et al. 2009; Moldan et al. 2012 and EPA et al. 2012, 4f.). This de nition was extended in 1992 by the *Earth Summit* (UN), which followed into Agenda 21, and ultimately into the *World Summit on Sustainable Developmen*t (UN) in 2002 (Moldan et al. 2012).

In the course of the 2002 Word Summit, the concept of the interlocked *three pillars* of *sustainability* (consisting of a social, an economic and an environmental pillar) evolved (Moldan et al. 2012; Dahl 2012 and EPA et al. 2012, 4f., see Figure 1) and is nowadays integrated by default into all important political/business and strategic documents (Moldan et al. 2012).

But this approach developed from rather unspeci c notions describing the term sustainable development and needs to be complemented by speci cations (e.g. clear indicators) (Moldan et al. 2012), which, as discussed above, is problematic in itself -also because the choice of indicators re ect on values (Meadows, 1998, as cited in Singh R. R. et al. 2009).

At the same time this vague basis is also one reason why attempts to measure sustainability generally focus on one of the three aspect (Singh R. R. et al. 2009), resulting in a strong need of cross-sectoral approaches (Misselhorn et al. 2012), to do justice to the holistic demand of the concept. But this demand is what makes it incredibly problematic, and as a consequence virtually impossible to work with altogether.

As the Austrian freelance writer, journalist and playwright Marlene Streeruwitz stated at a congress[1] held in Vienna *"Kunst, die ich nicht so nennen will, weil ich etwas anderes haben möchte"* (loosly translated as *"art which I do not want to call art, since I wish for another word"*) and who further stressed for the requirement of a *new language* which aims to enable us to describe and talk about a *good life for all*[2]. In her opinion such a language does not yet exist.

[1] Congress, titled *Gutes Leben für alle* (good life for all), 20.-22.02.2015, at the Vienna University of Economics and Business. *See also http://www.pfz.at/article1726.htm, last accessed on 22nd april 2015.*

[2] *Good life for all* was the title of the congress

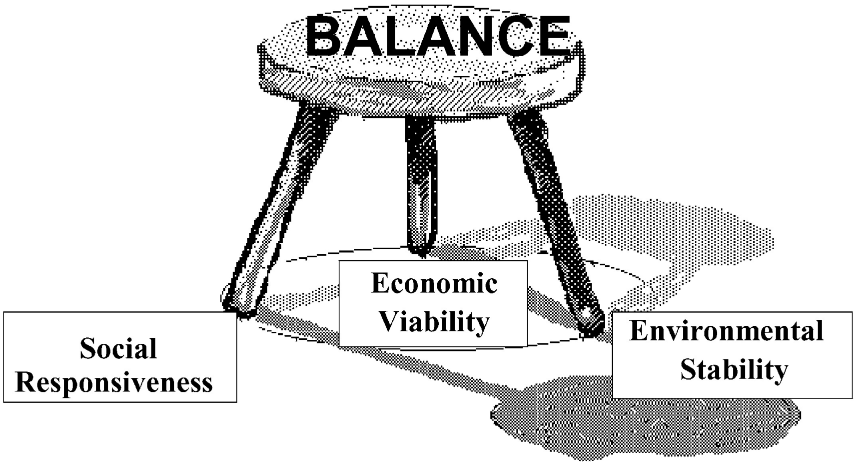

Figure 1: Three pillars of agricultural sustainability

Source:Doran (2002).

A statement which is aligned with thoughts of philosophers (e.g. Wittgenstein), who stress the necessity to articulate our thoughts, because we would not be capable to think them otherwise. Seemingly, these thoughts also apply for the sustainability concept, highlighting the need for interdisciplinary dialogues (see Chapters 3.1.4.2.8 on Resilience and 3.1.4.2.4 on the Malthusian concept).

1.1.2 The concept of *soil health*

Soil serves as basis for plant growth (Doran and Zeiss 2000), for food- and bre production (Doran 2002). Acknowledging this aspect in combination with a growing awareness of problems associated with soil degradation- and erosion processes (Doran and Zeiss 2000) helps drawing attention towards issues related to *soil quality/health.*

The terms *soil health* and *soil quality* are strongly connected and, despite slight differences, are sometimes used synonymously (Doran and Zeiss 2000). S*oil quality* for instance is desrcibed as

> *"[t]he capacity of a specific kind of [vital* (Doran and Zeiss 2000) *living* (Doran 2002)*] soil to function within natural or managed ecosystem boundaries, to sustain biological productivity, maintain environmental [water and air* (Doran 2002)*] quality, and promote plant and animal health"* (Soil Society of America, 1997, as cited in Herrick 2000, see also Doran and Parkin, 1994, as cited in Zarea 2010, 216f.).

Harrick s de nition therefore highlights the balance between the interaction of biological, physical and chemical soil characteristics. Doran and Zeiss (2000) however noted that this de nition should rather be used to describe soil *health*, as it is their opinion that soil *quality* should place a stronger emphasis on the soil s tness. Their argumentation is based on the de nition given by Johnson et al. (1997, as cited in Doran and Zeiss 2000) who de nes soil quality as *a "[...] measure of the condition of soil relative to the requirements of one or more biological species and/or to any human purpose"* (Johnson et al. 1997, as cited in Doran and Zeiss 2000). Therefore some researchers would prefer the term soil *health* over the term soil *quality,* because the rst one would draw stronger attention to soil being perceived as a dynamic and living system. Additionally the use of the term soil *health* is also hoped to support a mindset which allows for a more implicit perception of e.g. soil organisms, as well as enhanced awareness of soil as an in uenceable, adaptive system (in a positive and a negative way). Subsequently the use of the term aims at supporting the recognition that soil requires smart management strategies, conservation practices and sustainable land-use decisions (Doran 2002 and Doran and Zeiss 2000). In the following the topic will consequently be referred to as *soil health.*

In order to determine the degree of success of e orts to preserve and improve soil health in agriculturally used acreage over time, a list of indicators have been chosen. These indicators include e.g. physical and chemical properties of soil (Doran and Zeiss 2000). Although Herrick (2000) points out that soil health has itself risen to be an integrative indicator, as it constitutes the basis of almost all land-use purposes. In this role it helps to mirror impact of land-use/land-use change and supports conducting evaluations on issues related to e.g. *food security* (see Chapter 3.1.4.2.2 on Food Security) and economic viability of environments (see also Chapter 3.1.2.4 on Tillage systems). In contrast Popp et al. (2000) state that any attempt in assessing an environmental condition would be di cult or even problematic due to the inherent complexity of ecosystems. It is their opinion that these issues would not properly be captured by using the term soil health, because such simplistic terms would insu ciently try to summarise the complexity and squeeze them into a nutshell. Nevertheless, they do acknowledge the importance of complexity presented in a nutshell, as such compact parcels would exactly t the requirements of policy makers, enabling them to adequately deal with complex problems and come to knowledge based solutions.

However, the selection of indicators[3] is a delicate process, as it is always related to a

[3] See also the statement from Meadows (1998, as cited in Singh R. R. et al. (2009)) mentioned in the section about sustainability, who stated that the choice of indicators is problematic by itself, as the

certain purpose and a speci c setting (regardless of the degree in awareness) and therefore never impartial (Popp et al. 2000). In other words, depending on the aim, indicators need to be handpicked (see also Herrick (2000)). Consequently it is a di cult task to compare diverse indices.

Today the most commonly used indictor to evaluate *soil health* is the soil organic matter (SOM) content (see Chapter 3.1.2.4 on SOM) (Doran and Zeiss 2000). Still, opinions on most valuable indicators cover a broad spectrum. Popp et al. (2000) for example emphasise the importance of water capacity, bulk density, pH, organic matter and rooting depth.

Moreover in order for soil health to be classi ed as being sustainable certain thresholds need to be respected. Particular focus should be placed for example on maintaining a certain magnitude of average crop yields, a certain range of pro ts, a minimum amount of soil depth, a minimum share of soil cover, as well as a minimum risk of crop failure (Doran and Zeiss 2000).

However, if the main purpose of using the soil health concept was simply the raise awareness of the importance of soil e.g. amongst practicioners, main tasks would focus stronger on the need to o er useful, easily applicable, quick and inexpensive measurements. Nonetheless all kinds of indicators should be sensitive towards land-use changes and should consequently act elaborative on ecosystem processes (Doran and Zeiss 2000). This goal illustrates the focus on the process-orientated objectives related to soil health quite vividly. Still, this approach also causes di culties as soil processes such as mineralization[4], macropore formation or decomposition generally call for expensive measures which usually need to be exercised by more experienced hands. Consequently this process-oriented approach needs to rely on readily available, inexpensive and easily appicable indicators in order to be able to detect, capture and map e.g. links between causes and e ects. This could be an option with regards to detailed processes such as links between

choice reflects certain values.

[4]Mineralization describes a process in which organically bound N is converted into inorganic mineral forms. Different soil microorganisms hence decompose carbonaceous organic residues and hydrolyze these organic N compounds. Through this process they produce inorganic NH_4^+ and NO_3^-ions. However soil organisms may need more nitrogen than the amount available in the soil or derived from crop residues. In this case they incorporate mineral N into their cellular constituents (e.g. as proteins). This process is called immobilization and describes the counter-process to mineralization. It involves microorganisms dying and decomposing. Some of the mineral N incorporated by the microorganisms may form part of the humus complex, or may be released as NO_3^- and NH_4^+. Generally these two processes, mobilization and immobilization, occur simultaneously. The net result of plant available mineral N hence depends mostly on the C:N ratio in the organic residues that are decomposing (Brady and Weil 1999, 495f.).

organisms and water storage/nutrient cycling/decomposition or detoxification processes, as well as between land-use change on environments on a broader scale (Doran and Zeiss 2000; Herrick 2000 and Zarea 2010, 213).

Besides farmers could easily participate if using indicators like the number of earthworms[5] which in almost all cases would fit the needs of practitioners sufficiently in terms of accessibility, affordability and easily-applicable monitoring systems which do not require extensive training (Herrick 2000, see also Doran and Zeiss 2000; Zarea 2010, 209 ff. and Pretty 2005, 2).

An additional benefit in using soil organisms and biotic parameters which are visible with the bare eye and well identifiable, is the little taxonomic knowledge which is needed to apply them as an indicator. Alongside earthworms other easily spottable and highly recognisable *indicator organisms* include insects or moulds (Doran and Zeiss 2000 and Zarea 2010, 213).

However with respect to the selection of organism(s) which are considered to be most suitable for monitoring, opinions are contradictory, as first and foremost the chosen organisms would need to be viable and consistent over time themselves in order to guarantee successful and meaningful long-term monitoring. These requirements are consequently vital for long-term monitoring which themselves would be crucial to detect and evaluate developments such as anthropogenic impact over time (Herrick 2000 and Popp et al. 2000).

Moreover, when applying indicators in order to compare different land management systems sometimes only significant differences are detected while more subtle changes may remain unnoticed. This would further pose the risk of consolidating current believes as well as decreasing the probability of opening up new perspectives. Even more severe consequences would for instance include the prevention of identifying new/different early warning markers. This aspect is particularly relevant as reactions which may capture changes amongst early warning indicators may take place in a time-delayed manner (Herrick 2000).

Herrick (2000) hence stresses the need to a) predict responses of a system towards disturbances and to b) illustrate relationships between soil health and ecosystem functioning, as demonstrated by biodiversity, biomass production and soil-water resources. For example if the share in soil carbon would increase, microbial biomass would subsequently be

[5] Further details on positive effects of earthworms on physical, chemical and biological properties of soil are summarised in [Zarea, Mohammad J. Conservation, Tillage and Sustainable Agriculture in Semi- and Dryland Farming. Springer (2010), 195-238], especially on the pages 209-213.

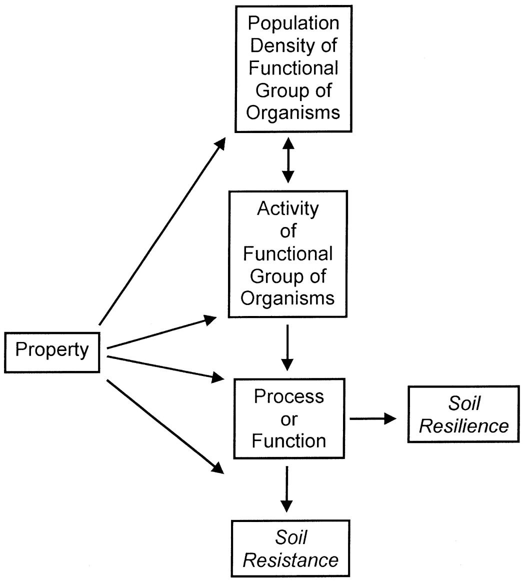

Figure 2: Illustration of required connections that need to be surveyed for each indicator.

According to Herrick (2000), all depicted connections need to be described and quanti ed for each indicator in order to be e ective. The illustration shows links that are likely to be found between soil properties/processes/functions and soil resistance. Source: (Herrick 2000).

enhanced dramatically, as would be the soil organic matter content, followed by an improved in ltration and cycling of nutrients. In order to emphasis stronger foci on *responses* and feedback mechanisms to impact, Herrick (2000) suggests the implementation of the approaches of resilience and resistance (see Chapter 3.1.4.2.8 on Resilience).

In summary soil health is considered to be an essential indicator in assessing and promoting sustainable land management strategies. However embedded in the context of changing landscapes and time the concept would need to be complemented by other approaches, such as resilience, in order to be more e ective (as illustrated in Figure 2) (Herrick 2000). Herrick (2000) further stresses the need for transdisciplinary and creative approaches, while being perfectly aware of the lack of supporting structures o ered in current frameworks.

2 MATERIALS AND METHODS

The thesis is based on literature research and complemented by practical experience, discussions and site visitations with experts gathered during ve months of project related work at the Chamber of Agriculture in Upper Austria, Department Plant Production in 2014.

2.1 Description of the soybean plant, its required growing conditions and a short history of its origin

2.1.1 Botanical description

Soybean (*Glycine max [L] Merr.*) is a grain legume as well as an oilseed (Diepenbrock et al. 2005, 199) and an annual short-day plant with a habitus comparable to that of bush beans, a height of 30-200 cm (depending on cultivar among other factors) and a chromosome number of 2n = 40 (Diepenbrock et al. 1999, 245 and Qiu and Chang 2010). The caulius is round in shape, upright, with long, petiulated and mostly trifoliolate leaves, which are arranged in an alternating way on the top part of the plant and opposed to each other at the bottom (Diepenbrock et al. 1999, 245).

Growth types include a) indetermined varieties, which keep elongating after owering, as well as b) determined types, which stop stem elongation as soon as owering period sets in. In soybean breeding varieties between both growing types are constantly improved, although most commercial varieties in Austria belong to the indetermined growth type. In addition, this trait (growth type) is correlated with growing height and plant stability (Mechtler 2012).

In cooler cropping areas such as Switzerland, determined or half-determined growth varieties proved to be more suitable, even though determined growth varieties resulted in reduced yield stability compared to indetermined ones (Schori et al. 2003).

Soybean owers are small with a owering period that lasts between 20 and 40 days (with some reported exceptions of owering periods of up to 90 days (Egli 2010, 118)). Flowering sets in predominantly through temperature and daylength, although in early ripening varieties, owering is mainly induced by temperature and hardly a ected by daylength, while in contrast, owering in later ripening varieties is primerily initiated by daylength (Olechowski and Upfold n.d.). Moreover, varieties with a large quantity of owers lose the majority during anthesis, while varieties with low numbers of owers abandon very little of them (Panthee 2010, 95 .). In addition, soybean is a strictly selfpolllinating plant (99%) due to its cleistogamous, enclosed pollination (Panthee 2010, 95 .). Combined with the small size of the owers, e.g. crossings become rather delicate challenges to perform in soybean breeding.

Pod size, shape and colour di er according to variety and range between 2-6 cm in size and 1-6 seeds per pod (Schuster et al. 2000). Seeds di er in colour (but are mostly yellow, brown, black and green), they are usually evenly coloured, marbled or sprinkeled and are shaped round to oval with speci c colouring of the navel. The thousand seed weight is also cultivar-speci c and ranges between 45 to 480 g (Kumundi 2010, 52 . and Schuster et al. 2000).

Epigeic germination[6] (see also Chapter 3.1.2.5) is induced through soil moisture content, temperature and sowing depth and should require approximately a fortnight after sowing (Olechowski and Upfold n.d.), in the case that both soil- and air temperatures reach at least 13-16°C (Singh G. et al. 2010, 144f.).

Seed initiation only starts after the full pod size is reached (Olechowski and Upfold n.d.) but 70-80% of all pods that are grown by a singe plant will start appearing during the rst 12 days of pod-growing stage. The other pods will follow during the subsequent 30-40 days (Egli 2010, 118).

2.1.2 Root structure

The rootsystem of soybeans consists of a modi ed tap root and numerous lateral roots (Mechtler 2012 and Diepenbrock et al. 1999, 245), with the whole rootsystem developing rather quickly (Soldati 1999, 677f.). The rooting depth is reported to be 60cm on average, but was stated to be up to two metres (Diepenbrock et al. 1999, 245).

2.1.3 Origins and how *Glycine max* came to Austria

3000 to 3500 years ago, *Glycine max* was most likely cultivated at multiple places in southern China. The original species was the annual, non-domestic species *G. soja* (Mishra and Verma 2010, 74 and Qiu and Chang 2010, 2f.). Evidence supporting this hypothesis is provided through synchronized owering in the Yellow River Valley (35°N) between cultivated and wild soybean variations, indicating that both are short-day plants. In addition they also show similarities in the protein contents (Qiu and Chang 2010, 3 .). Approximately 2000 years ago soybean was introduced to Japan and Korea, before reaching the

[6] An epigeic germination implies that the bent hypocotyl reaches soil surface first, and cotyledons are pulled up afterwards (Kumundi 2010, 52ff.; Mechtler 2012; Olechowski and Upfold n.d. and Soldati 1999, 678).

Figure 3: Side-by-side cultivation of different maturity groups

The picture highlights the available variation concerning the maturity group. The photograph was taken at an experimental site of the *University of Natural Resources and Life Sciences* in Groß Enzersdorf, Lower Austria, 2014.

United States in the 1950s, Brasil 1961 and Argentina (Qiu and Chang 2010, 18f.). In Istria, South Tyrol and the Ukraine trials with *Glycine max* first started in 1840. In Austria and Hungary university professor Friedrich Haberlandt at the University of Natural Ressources and Life Sciences led in introducing and spreading soybean and its popularity amongst plant breeders after 1875 (Schuster et al. 2000, see also Haberlandt 1878).

2.1.4 Maturity groups

Glycine max is classified into groups according to ripening times which are connected to reactions of the photoperiod as well as of accumulated positive temperatures. On a global scale there are 13 maturity groups of soybean (000, 00, 0 I-X) (Mechtler 2012 and Schori et al. 2003). This internationally used system with 13 maturity groups is commonly found in the US, whereas cultivars in China for instance are described in terms of early- mid- and full-season cultivars. The Chinese classification system is therefore more site-specific and refers primarily to regions rather than to cultivars. For instance, in different regions, one cultivar may be classified into different maturity groups, depending on the growing characteristics this cultivar shows in each of the regions (Liu et al. 2008). Early maturing groups (000 to II) are reported to have a lifecycle of 140 to 150 days from seeding date to ripening stage (Diepenbrock et al. 1999, 248f. and Soldati 1999, 673; see Figure 3).

In Austria 000 (very early) and 00 (early) varieties are in regular cultivation, whereas 0000 (extremely early) varieties are still being tested. Up to now however the results were not convincing enough (Brandstetter et al. (1993, 2); Diepenbrock et al. (1999, 248) and Mechtler (2012)). Brandstetter et al. (1993, 2) stated that cultivation of 0000-varieties in Austria would only be a suitable option in sites with favourable condition and lower than 500m above sea level. On a global level 000-varieties are also cultivated in Canada and northern Europe, 00-varieties are also found in Central Europe, Canada, North America and 0 and I-varieties are well adapted to maritime climate. II-X maturity groups on the other hand are not suitable for cultivation in moderate climates (Soldati 1999, 665).

In moist and comparatively cool cultivation areas in Austria (e.g. in foothill zones of the Alps or more generally speaking Upper- and Lower Austria), 000-varieties are the predominantly used varieties. Because of the conditions found in these areas the ripening times of these maturity groups match best, although ripening differences even within one maturity group could be up to 8 (Mechtler 2012) or 10 days (Brandstetter et al. 1993, 2) between different cultivars. The ripening time is also influenced by other factors such as water and nitrogen (N) supply, bacteria and the previous crop within the crop rotation (Brandstetter et al. 1993, 2).

2.1.5 Soil/site requirements

Soybean is a thermophilic short-day plant (Diepenbrock et al. 1999, 247) which requires rapidly warmable soil combined with a slightly acidic to neutral pH value (ranges between 6 - 7.5) (Brandstetter et al. 1993, 2; Diepenbrock et al. 1999, 247; Pistrich et al. 2014, 14 and Soldati 1999, 672f.). A suitable pH value is especially important for successful nodulation (see Chapter 3.1.2.9.1 on Infection in BNF) and hence for efficient biological fixation of atmospheric nitrogen (Brandstetter et al. 1993, 2; Friedel et al. 2003 and Soldati 1999, 672). Therefore highly acidic soil types could be limed in order to adjust soil pH and consequently offer more suitable conditions for rhizobacteria (Friedel et al. 2003).

Soil appropriate for soybean cultivation should have profound depth, medium weight (Diepenbrock et al. 1999, 247: Mechtler 2012 and Soldati 1999, 672) and should possess high water-holding capacity combined with high organic matter (OM) content (Mechtler 2012 and Diepenbrock et al. 1999, 247). Higher advantages are also offered by soil types that are rich in nutrients (Diepenbrock et al. 1999, 247), as well as locations with low weed pressure (see Chapter 3.1.2.8 on Competitiveness against weeds). Less suitable are sites with light, sandy, alkaline or aggregated soil that lack in depth. Soil types like these would be more susceptible towards drought or siltation which would ultimately cause yield loss (Soldati 1999, 672).

2.1.6 Temperature and climate requirements

Best growing conditions for soybeans include moist and warm climates with high accumulated positive temperatures and a continuous supply of water (Brandstetter et al. 1993, 2 and Soldati 1999, 672). Seemingly, humid climate is most suitable for grain legumes in general (Mechtler 2012).

The accumulated positive temperature during the whole growing period should have a value between 2 100 to 2 500° C, based on 0°C and water demand of 500 mm precipitation. But considering both factors (precipitation and temperature), distribution is probably more important than the sum itself, as soybean has certain developmental stages in which it is considerably more sensitive towards unsuitable temperatures or inadequate water supply than in others. If less suitable environmental conditions are encountered during such a sensitive developmental stage yield loss might be dramatic. To give an example, soybean has higher water demands when the owering stage sets in, during pod growth and the grain lling stage, whereas during youth developmental stages and the ripening stage drier weather conditions are more favourable for achieving higher yields (see Chapter 3.1.2.12 on agronomic soybean breeding targets) (Mechtler 2012). Consequently, during owering, pod growing and the grain lling stage adequate and constant water supply is important and has been reported to be 300 mm minimum (Diepenbrock et al. 1999, 247: Mechtler 2012; Pistrich et al. 2014, 55 and Soldati 1999, 672). This is also why Diepenbrock et al. (1999, 247) do not like to describe *Glycine max* as a drought resistant plant species.

Elevated temperatures are very suitable preconditions for soybean cultivation, with a minimum germination soil temperature of 8-10°C (Diepenbrock et al. 1999, 247 and Soldati 1999, 672). Late frost events on the other hand might permanently damage soybean seedlings up to a degree in which seedlings cannot recover and subsequently weed pressure might intensify (see Chapter 3.1.2.1 on planting dates) (Mechtler 2012). Generally, seedlings may tolerate temperatures as low as -2 °C (Diepenbrock et al. 1999, 247).

An optimum temperature for growth would range between 20 and 25°C. Such high temperatures are particularly important during the months July to September (Soldati 1999, 672), because cold weather events during owering period would lead to an increasing abandonment of owers and pods leading to yield loss (Mechtler 2012 and Pistrich et al. 2014, 55). There also seem to be connections between temperature, climate and seed quality and seed composition (see Chapter 3.1.3.2 on consumption related breeding targets).

To summarise, restrictions to suitable production areas include low temperatures (especially during owering period), day length, low accumulated positive temperatures below 140-150 days, insu cient water supply (particularly during owering and pod- lling stage) and elevated locations above 500-550 m above sea level (Schori et al. 2003).

2.2 Methods of research

The thesis is based on a literature review. In order to nd relevant literature (especially with respect to monographies and edited volumes) I consulted di erent University libraries in Vienna and used the option of library loans to access items from international libraries. The multitude of scienti c papers, which I was authorised to access as enrolled student at the University of Natural Ressources and Life Sciences, was mostly found through consulting online databases and consortia like Elsevier (Science Direct), Springer and Wiley.

I was also given the opportunity to work in the Chamber of Agriculture in Upper Austria for ve months. In this position I was able to conduct non-formal interviews and elaborative discussions with practitioners, experts, members of soybean-processing industries, policy makers and other stakeholders involved. In addition I was permitted to conduct site-visitations of various trials all over Austria (mostly in Upper Austria but also in Burgenland, Carynthia, Styria, and Vienna).

3 RESULTS

3.1 Status Quo

3.1.1 Current global and national soybean cultivation in figures

3.1.1.1 International soybean production and trade As shown in Figure 4, on a global scale, soybean acreage was subject to certain uctuations, but all in all showed a rather steep rising tendency. For illustration purposes let s look at developments of the global soybean acreage between the years 1961 and 2013. Within these 52 years, soybean acreage rose from 23.8 m hectares in 1961 to 111 m hectares in 2013 (which equals a 4.6 fold increase (FAOSTAT 2014, last accessed on 27th Oct 2014). Such a development was made possible solely through extending cropping areas on a vast scale within short periods of time. Similar developments were recorded for example during the years 1972, 1977 and 1997.

From a geographical point of view the greatest increases were registered almost exclusively in the Americas where cultivated areas enhanced from 21.2 m hectares in the year 1972 to 85.6 m hectares in 2013, which is a quadruplication in 41 years (FAOSTAT 2014, last accessed on 27th Oct 2014). In Asia soybean acreage doubled within 36 years which is a slightly less steep increase compared to the Americas. In gures this means a gain from 8.6 m hectares in the year 1977 to 20.6 m hectares in 2013 (FAOSTAT 2014, last accessed on 27th Oct 2014). Europe on the other hand had more than quadrupled its soybean acreage in 52 years (between 1961 and 2013), most recently 3.1 m hectares in 2013 (FAOSTAT 2014, last accessed on 27th Oct 2014).

What might also become clear from Figures 4, 5 and 7 is that European soybean acreage as well as production volume are negligible compared to magnitudes on a global scale. Nevertheless, the continuing dramatic increase in soybean cultivated areas on a global level concludes that soybean production is still gaining in importance (FAOSTAT 2014, last accessed on 27th Oct 2014). Similar trends can be seen in Austria, where Pistrich et al. (2014, 27) point out that there is no other crop in Austria with a comparable development in respect of its rising popularity.

Historical developments of soybean production, as depicted in Figures 5 and 6, illustrate a continuously rising trend which is tightly correlated with the huge expansions in soybean acreage in the Americas just mentioned. In the year 2013 for example, the total production volume of soybean was 276 406 002 metric tonnes, with the share of the Americas on the total volume being 87% (see Pie Chart 7). In comparison the European share was 2%

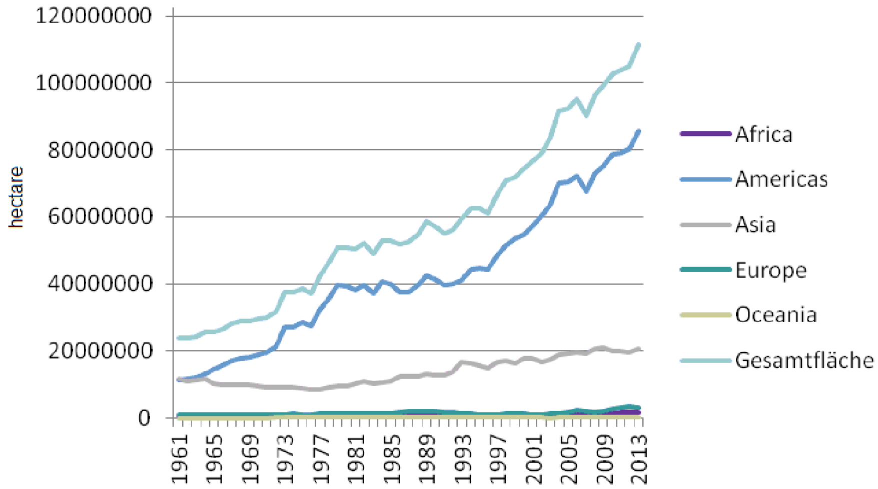

Figure 4: Development of the global soybean acreage

Source: FAOSTAT 2014, last accessed on 27th Oct 2014.

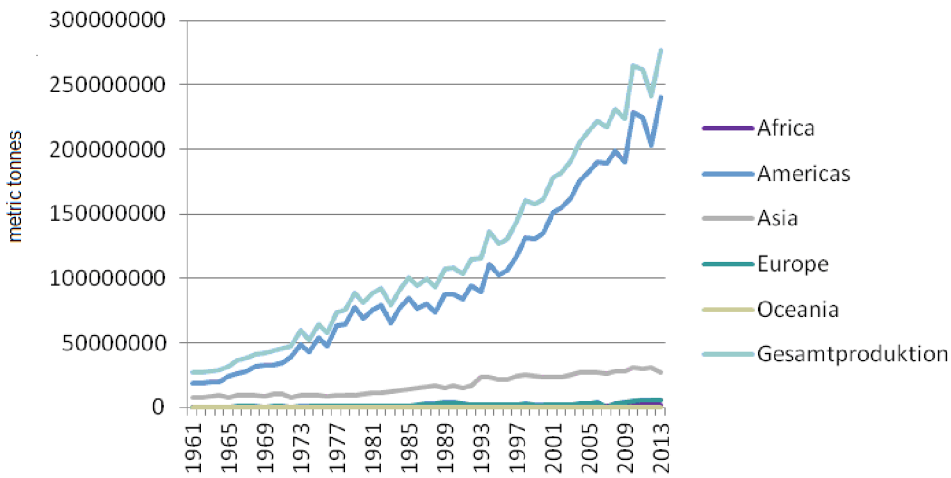

Figure 5: World total production of soybean in metric tonnes

Source: FAOSTAT 2014, last accessed on 27th Oct 2014.

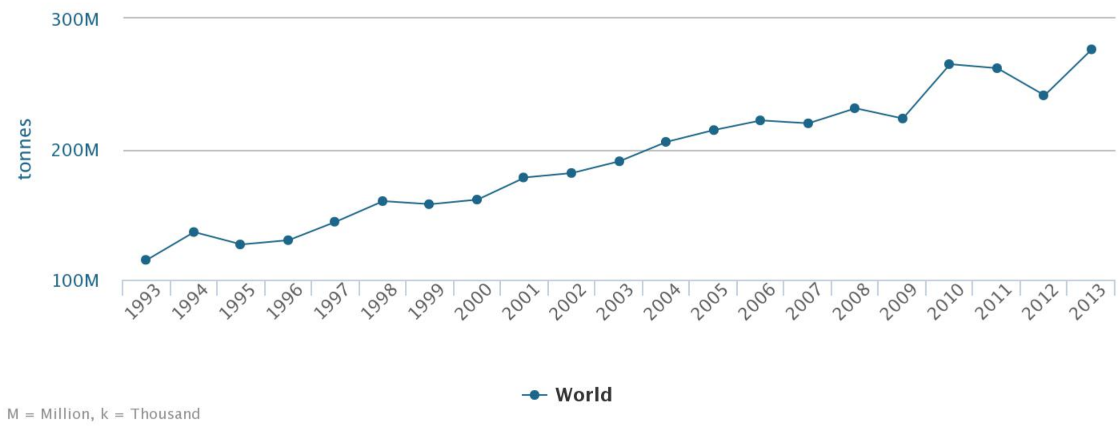

Figure 6: Development of global soybean production between 1993 and 2013

Source: FAOSTAT 2014, last accessed on 27th Oct 2014.

(FAOSTAT 2014, last accessed on 27th Oct 2014).

According to FAOSTAT, in the year 2013, the USA produced about 89.5 m metric tonnes of soybeans, which equals 32.4% of the total world production and an average yield of 2.9 metric tonnes per hectare. In 2012/13 -according to FAOSTAT - the USA was number one soybean producer, followed by Brazil with 81.7 metric tonnes, which is 29.6 % of the total world production with 2.9 metric tonnes per hectare. And the third largest producer in the year 2013 being Argentina with 43 m metric tonnes, which is a share of 17.8 % of the total world production and an average yield of 2.5 metric tonnes per hectare (FAOSTAT 2014, last accessed on 27th Oct 2014).

Toepfer (who uses data from USDA) presents slightly alternating gures resulting from using scal years, which are presented in Table 1 (where the major soybean producers of the past 5 years are listed). They draw a little di erent picture and according to the data they published, Brazil overtook production volumes of the USA in the scal year 2012/2013.

3.1.1.1.1 International export On a global scale, 98.9 m metric tonnes of soybean were exported in the scal year 2012/13 (USDA, as cited in Toepfer 2013.). Main exporting countries of whole seeds during the same timeframe were Brazil (38.4 m tonnes), USA (36.6 m tonnes) and Argentina (11 m tonnes) (USDA, as cited in Toepfer 2013. and Pistrich et al. 2014, 13; 27 .).

According to Pistrich et al. (2014, 33), 170 m metric tonnes of soybean extraction meal

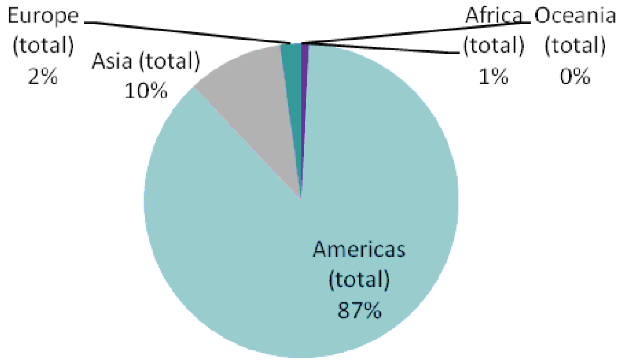

Figure 7: World total production in metric tonnes

The data is presented as pie chart. Sorce: FAOSTAT 2014, last accessed on 27th Oct 2014.

Table 1: Soybean production in m metric tonnes for economic years

Soybean production	**In m tonnes**				
	2008/9	**2009/10**	**2010/11**	**2011/12**	**2012/13**
USA	80.75	91.42	90.61	84.19	82.06
Canada	3.34	3.59	4.45	4.30	4.93
Brazil	57.90	69.00	75.30	66.50	82.50
Argentina	32.00	54.50	49.00	40.10	54
Paraguay	3.65	6.46	7.13	4.36	7.75
Bolivia	1.60	1.67	2.30	2.32	2.40
PR of China	15.54	14.98	15.10	14.48	12.60
India	9.10	9.70	9.80	11.00	11.50
Uruguay	1.17	1.82	1.55	1.60	1.90
World	**211.64**	**260.25**	**263.59**	**238.73**	**269.41**

Source: USDA as cited in Toepfer 2013.

Table 2: Export soybean in fiscal year 2012/13 in m metric tonnes

	2010/11	2011/12	2012/13
Brasil	30.0	36.3	38.4
USA	40.8	37.1	36.6
Argentina	9.2	7.4	11
World	**91.1**	**90.4**	**98.9**

Source: USDA, as cited in Toepfer 2013.

and whole soybean seeds were traded in the scal year 2011/12. Also, in the scal year 2012/13, whole soybean seeds constituted the major share in global trade volumes. During this period of time 99 m metric tonnes of whole seeds and an additional approximate 60 m metric tonnes of soybean extraction meal were exported. The main exporting country of soybean extraction meal was Argentina (with 28 m metric tonnes in the scal year 2012/13), followed by Brazil (with roughly 14.7 m metric tonnes) and USA (with less than 8 m metric tonnes) (USDA, as cited in Toepfer 2013). With respect to soybean meal 183 m metric tonnes were produced on a global level in scal year 2012/13. Main producer was the PR of China with 52 m metric tonnes, followed by the US with 34.9 m metric tonnes, Argentina with 29.1 m metric tonnes and Brazil with 28.6 m metric tonnes (USDA, as cited in Toepfer 2013).

3.1.1.1.2 International import As listed in Table 3, the main import country of whole soybeans in scal year 2012/13 was the PR of China with 63 m metric tonnes, followed by the EU-27 with 11.3 m metric tonnes, Mexico with 3.4 m metric tonnes and (not listed) Japan with 2.8 m metric tonnes (USDA, as cited in Toepfer 2013).

The PR of China has been the main importing country ever since the scal year 2002/03 with respect to whole soybean seeds. Over 10 years ago, it replaced the EU-27 as major importing country in respect of whole soybean seeds (Pistrich et al. 2014, 34 and (USDA, as cited in Toepfer 2013). This development was rooted in changing consumption patterns and nutritional habits including the rising meat consumption in the PR of China, implying an enhanced demand in proteins (see Chapter 3.1.4.2.1). Concerning soybean extraction meal, members of the EU-27 were considered to be the most important importing countries with 21 m metric tonnes in the scal year 2012/13, followed by Indonesia with 3.1 m metric tonnes, Thailand (2.8 m metric tonnes) and Japan (2.4 m metric tonnes) (USDA, as cited in Toepfer 2013). But Pistrich et al. (2014, 36) also point out that the market of soybean extraction meal is in itself less dynamic in its development compared to the market of whole soybean seeds.

3.1.1.1.3 Soybean production in the EU In the EU-27 less than 1.2 m metric tonnes of soybeans were produced in the scal year 2012/13 (see table 4). In the EU-15 998 000 metric tonnes and in the EU-12 only 177 000 metric tonneswere produced during the same period of time. Within Europe leading soybean producing countries in the scal year 2012/13 were Italy (810 000 metric tonnes) and France (109 000 metric tonnes), followed by Romania (84 000 metric tonnes) (ACTI, as cited in Toepfer 2013). With

Table 3: Import of whole soybeans in the fiscal year 2012/13 in m (metric) tonnes

	2010/11	2011/12	2012/13
PR of China	52.3	59.2	63
EU-27	12.5	11.8	11.3
Mexico	3.5	3.4	3.4
World	**88.8**	**93.1**	**96.5**

Source: USDA, as cited in Toepfer 2013.

Table 4: Soybean production within the EU as an example in 1 000 metric tonnes

	2010/11	2011/12	2012/13
EU-27	940	1 258	1 175
EU-12	150	227	177
EU-15	790	1 031	998
Italy	578	828	810
France	140	123	109
Romania	59	130	84
Austria	70	78	77
Hungary	69	73	70

Source: ACTI, as cited in Toepfer 2013.

77 000 metric tonnes Austria produced about the same amount of soybeans as Hungary (70 000 metric tonnes) during the same period of time (ACTI, as cited in Toepfer 2013). What also can be seen from Table 4 is that the soybean production volumes of single countries are unequally distributed throughout Europe.

(Pistrich et al. 2014, 47) emphasise that the EU - up to now - were unable to cover all needed amounts in soybeans by themselves, although the EU s import volumes show a regressive trend with simultaneously increasing production volumes (1 070 364 metric tonnes in 2013 (FAOSTAT 2014, last accessed on 27th Oct 2014) compared to 863 000 metric tonnes in 2012 (Pistrich et al. 2014, 45). This illustrates a clear trend in the EU towards less dependency on soybean imports. For instance, during the nancial year 2012/13 the EU imported 11.3 m metric tonnes of whole soybean seeds and 21 m metric tonnes of soybean extraction meal (cf. Toepfer 2013), which is far less than in the scal year 2011/12, in which 12 m metric tonnes of whole soybean seeds and 22.6 m metric tonnes of soybean extraction meal were imported (Pistrich et al. 2014, 45).

3.1.1.2 Soybean production and trade in Austria Intrigued by soybeans after the Vienna World Exposition in 1973, Friedrich Haberlandt, an agronomist and professor at the University of Natural Resources and Life Sciences in Vienna, became a pioneer in introducing the soybean in Austria as well as generating interest amongst fellow agronomists (cf. Haberlandt 1878). The Food and Agriculture Organization of the United Nations (FAO) however has only registered arable land dedicated to soybean production in Austria since 1988, in that year the production being 9 176 metric tonnes (FAOSTAT 2014).

During the 1990s soybean acreage in Upper Austria alone enhanced from 40 ha in 1987 to 700 ha in 1990 and up to 13 500 ha in 1992 (Brandstetter et al. 1993, 2). However coinciding with the entry into force of the Blair-House-contract, which a ected trade of oilseeds between Austria and the USA, the Austrian soybean acreage was drastically reduced (Soldati 1999, 661 .). A reduction of the soybean production was also registered after Austria joined the EU (Mairunteregg 2012, 8, see also FAOSTAT). Between 1990 and 2011 the amount of acreage harvested enhanced again, from 9 271 ha (1990) to 38 123 ha (2011), which meant a rise of 28 852 ha (or about 75.7%) in 11 years. At the same time the production of soybean enhanced from 19 046 hg/ha (1990) to 28 691 hg/ha (2011), which was an increase of 9 645 hg/ha (equalling 33.6%) (FAOSTAT 2014). Hence, not only soybean acreage expanded, but so did yields per hectare.

Figure 8 depicts the distribution of soybean acreage in Austria in 2013. The main production regions include Burgenland with a share of 31.3% on total soybean crop area in Austria 2014, as well as Upper Austria with a share of 30.2% on the total, as can also be seen in Table 5. The table also shows that those two federal states accounted for almost 62% of the whole Austrian soybean acreage in the year 2014.

The cultivated areas with soybean are almost congruent with those of grain maize (see Figure 9) and sugar beet (Pistrich et al. 2014, 55). If suitability and crop requirements in relation to cultivated areas are considered, 00-variations of soybean are in direct competition with the areas cultivated with sugar beet, sun ower or grain maize and could therefore be substituted, whereas 000-variations could be substituted with grain maize (Brandstetter et al. 1993, 2). This is important if farmers with regards to their net private incomes are considered, e.g. land-use change decisions (see Chapters 3.1.1.3 on economic aspects and 3.2).

This partitioning of soybean acreage throughout Austria is the result of regional growing

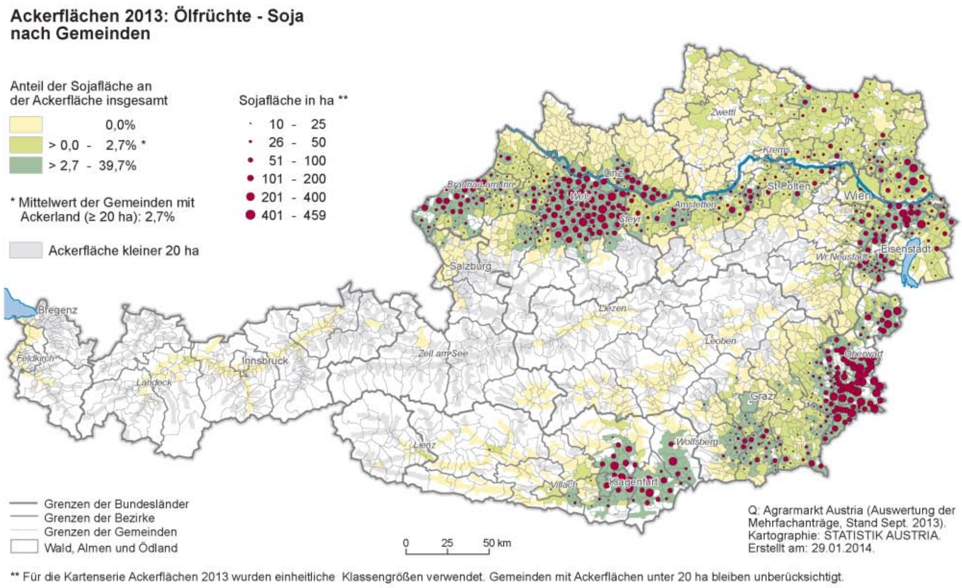

Figure 8: Soybean acreage in Austria illustrated according to towns in the year 2013

Source: Statistik Austria, 2014.

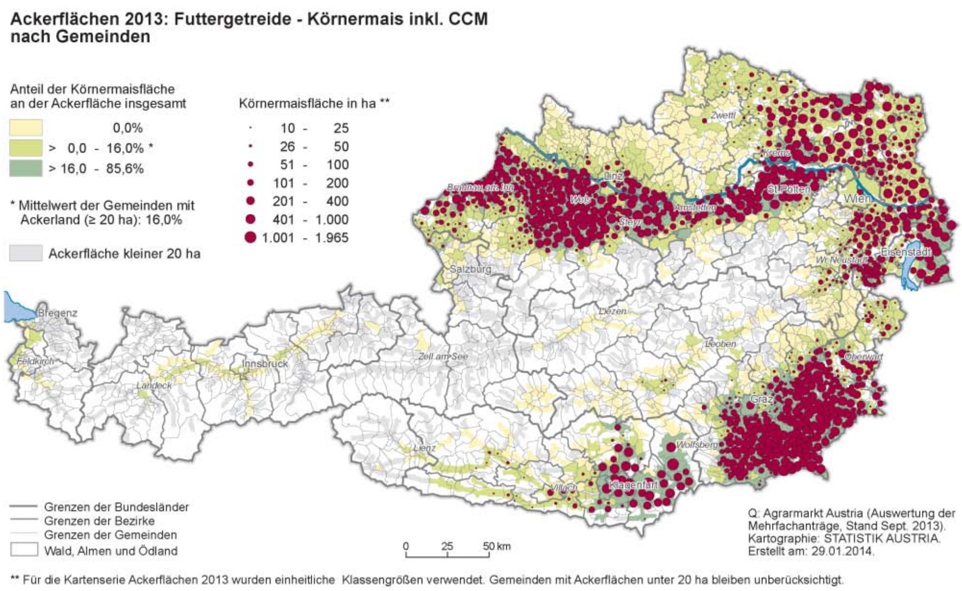

Figure 9: Arable land cultivated with grain maize in Austria 2013

Source: Statistik Austria, 2014.

Table 5: Arable land in hectare used for soybean production including organically grown soybeans.

Year	Austria (ha)	Burgenland	Carinthia	Lower Austria	Styria	Upper Austria
2014	43 680	13 687 (31.3%*)	3 205 (7.3%*)	10 349 (24%*)	3 124 (7.2%*)	13 204 (30.2%*)
2012	36 955	12 044 (32.6%)	3 067 (8.3%*)	7 548 (20.4%*)	1 989 (%.4%*)	12 222 (33.1%*)
2010	34 221	10 702 (31.3%*)	2 811 (8.2%*)	6 183 (18.1%*)	1 386 (4.1%*)	13 077 (38.2%*)

Source: AMA (2014) *) refers to % calculation based on numbers of whole harvest area of respecting year.

conditions as well as the distribution of soybean processing industries. Furthermore the distribution of livestock industries (especially pig farms), as they open markets and thus creat more favourable conditions for cultivating soybean nearby (LK OÖ and LK NÖ 2010), as an important consideration.

Concerning climatic conditions, the most suitable growing regions include the moist and warm south-eastern Austria, the rather warm climates in eastern Austria, a region in Lower Austria alongside the east-west train corridor (*Westbahngebiet*) (Pistrich et al. 2014, 55), as well as the so-called central region in Upper Austria (Brandstetter et al. 1993, 2).

Organic soybean production is steadily enhancing as well, especially in pannonic regions of eastern Austria, marked through average annual precipitation rates between 400 to 600 mm. In these regions soybean is predominantly cultivated for human consumption purposes (Schweiger et al. 2012).

3.1.1.2.1 National soybean acreage and seed yields Table 5 shows that soybean acreage in Austria increased by 9 280 hectares between 2010 and 2014, which is an extension of 21.2% in four years. Lower Austria in particular was able to enhance cropped areas with soybean from 20.4 to 24% over the last two years. Furthermore Table 6 demonstrates that in 2010 a total of 95 000 metric tonnes of soybeans were produced on a harvested area of 34 400 hectares, which are 27.5 dt/ha. The average yield between 2008 and 2012 was consequently 28.4 dt/ha (FAOSTAT 2014 and Statistik Austria).

In reference to the national soybean acreage, Krumphuber et al. (2013, as cited in

Table 6: Soybean acerage in reference to harvest and seed yield in recent years

Year	Area harvested (1 000 ha)	Harvest (one tenth of a metric tonne per hectare)	harvest (1 000 metric tonnes)	Production price (Euro per 1 000 kg)
2013	42	19.7	83	372.84
2012	37.1	28.1	104	466.76
2011	38.1	28.7	109	345.82
2010	34.4	27.5	95	323.15
2009	25.4	28.2	71	271.50
2008	18.4	29.4	54	327.70

Source: AMA 2014, see also FAOSTAT 2014 and Statistik Austria 2014.

Table 7: Arable land used for soybean production of organically grown soybean presented by most contributing districts

Year	Austria (ha)	Burgenland	Carinthia	Lower Austria	Styria	Upper Austria
2014	8 638	4 233 (49% *)	426 (5%*)	3 174 (37%*)	68 (1%*)	678 (8%*)
2012	6 735	3 294 (48.9%*)	505 (7.4%*)	2 400 (35.6%*)	9 (0.1%*)	504 (7.5%*)
2010	5 799	2 446 (42%*)	635 (11%*)	1 989 (34%*)	86 (2%*)	624 (11%*)

Source: AMA 2014, *) data calculated in reference to whole production harvest area of the whole year, in alphabetical order.

Seifried 2014, 94f.) predict an extension of 50.00 up to 60.000 ha soybean acreage to be realistic.

3.1.1.2.2 Organically farmed soybean acreage in Austria Table 7 shows the development of organically cultivated cropland in Austria within the last few years, as well as a comparison of the main soybean-producing federal states in alphabetical order over a time period of four years (2010-2014). In 2014 the share of organically grown acreage was 19.8% of the whole soybean cropland in Austria. The total expansion of organically grown soybean acreage from 2010 to 2014 was 2 839 hectares. Currently Burgenland dominates the organically grown soybean cropland with 49%, followed by Lower Austria with 37%.

3.1.1.2.3 National soybean trade The largest share of national imports falls upon soybean oilcake, which is a by-product of the oil extraction process and used primarily for animal feeding purposes. In the year 2012 431 000 metric tonnes of soybean oil cake were imported, which equals 548 000 metric tonnes of soybean seed equivalents (calculated in soybean equivalents, according to the calculation model of Pistrich et al. (2014, 51)).

Soybean meal and whole soybean seeds combined reached an import total of 101 000 metric tonnes in 2012. However very nely milled soybean extraction meal was imported in minor amounts and accounted for no more than 700 metric tonnes in 2012 (Pistrich et al. 2014, 51).

Of the share of all soybean imports, 87% are said to originate in genetically modi ed (GM)-soybeans, which seems plausible as GM cultivars are used on a regular basis in the Americas. Since all three of the world s leading soybean exporting countries (USA, Brazil and Argentina, see Table 1 and Chapter 3.1.1.1 on international soybean production) belong to the two Americas, it is hardly surprising that imports to Austria generally constitute large shares of GM-soybeans or related products like extraction meal.

Considering the exports from Austria, 69 000 metric tonnes of whole soybean seeds were exported in 2012, followed by soy oilcake with a share of 48 000 metric tonnes and 16 000 metric tonnes of soy extraction meal (Pistrich et al. 2014, 51).

3.1.1.3 Economic aspects and profitability of soybean production on a farm level

In Austria cultivated land that is suitable for soybean production is almost congruent with production areas of maize (Brandstetter et al. 1993, 2 and Statistik Austria). Nevertheless maize is still more established compared to the rather *recently* introduced soybean, even though the vermin *Diabrotica virgifera* causes major di culty and accounts for partially signi cant loss. Especially in Styria, where maize is needed as feeding material for swine industries, soybean and foxtail millet are hoped to defuse the situation caused by *Diabrotica virgifera* to some degree by extending crop rotations (Seifried 2014, 14;91).

Tables 8 and 9 list pro t contributions of di erent crops for comparison. According to the gures it seems as if soybeans cannot compete thoroughly with winter rapeseed, milling wheat, winter barley, maize or grain maize with elevated moisture content with respect to pro t expectations - at least not in 2011 and 2014 when these tables were published[7].

[7] Current policy decisions, especially in regard of the recently introduced obligatory *greening* constituent that was released in the course of the new Common Agricultural Policy (CAP) 2020, as well as due to rapidly changing agricultural subsidies would need to be considered in thoughts on economic net farm profits and land-use decisions Mitter et al. (2014, 132). In short„,greenings" for soybean cultivation

If the pro t contributions of soybean are compared to native protein delivering plants/-alternatives like fava bean, soybean shows best results (Luftensteiner et al. 2013 and Pistrich et al. 2014, 80). This aspect is partly connected to soybean s ability to x considerable amounts of atmospheric nitrogen biologically (BNF; see Chapter 3.1.2.9.1) - because BNF requires additional energy from the plant. This energy derived from photosynthesis. Legumes that x nitrogen biologically consequently need to generate extra energy compared to legumes that would receive mineral or organic fertilizer. Ultimately the ability of BNF is linked to trade-o s, like many other important plant traits are gained at the cost of others. The additional energy however always leads to constraints in other traits, e.g. reduced yields and lowered pro t constibutions (even in conventional agro systems). (Mechtler 2012, see also Chapter 3.1.2.12 on agronomic breeding targets)

By using stochastic dominance analysis in her master s thesis, Adele Theresa Seifried found that maize shows increased probabilities of producing higher economic results than soybean, because it s production is more likely to generate higher pro t margins. Seifried (2014, 89f.) based her analysis on market performance values and pointed out that speci c subsidies granted on a farm level had varied from farmer to farmer and were decoupled from speci c crops. Therefore she concentrated on market performance values. Her results showed that compared to maize cultivation, soybean production came with higher risks for lower net pro t contributions. But the performance of individual crops varies according to regions and environments as well. For instance in wetlands[8] soybeans were still o ering better overall performances than maize. Moreover Seifried stressed that governmental subsidies are most important on an individual farm level (e.g. *greenings*, see Footnote 7).

Seifried (2014, 90) hence argues that the choice upon the type of crop grown on farm level would always depending on highly individual contexts. Similarly Uri (2000) states that the *"[...] profitability is the main criteria for private economic (net private benefits) decisions* [...] . He refers to the choice of crop production practices and technologies in

in Austria entail the clearance of ecological compensation conservation areas for legumes starting with 2015, but may also refer to related/equivalent measures that are coherent with *Österreichisches Programm für umweltgerechte Landwirtschaft (ÖPUL)* (loosely translated as *Austrian program for environmentally sound agriculture*) standards. However, policy decisions and subsidies might change considerably in rather short periods of time compared to the relatively long time periods, soybean breeding targets would require further development and implementing. The dimensions of time within these two fields seem to be completely different and somehow difficult to be combined. In this thesis the aspect was not looked into with further detail, but for further reading please consult e.g. the following paper [Mitter H., Schmid E. and Sinabell F. (2014): Jahrbuch der Österreichische Gesellschaft für Agrarökonomie. 131-140].

[8]Seifried (2014, 89f.) referred to regions with specific characteristics as wetlands, in order to categorize data for market performances all over Austria. For more detailed definitions of her term *wetland* consult the original document, which is also available online.

Table 8: Profit contributions in comparison

procedure, in one tenth of a metric tonne/ hectare	milling wheat (wet-land)	winter barley	spring barley	grain maize	winter oilseed rape	soy-bean	fava bean
harvest	81.8	74.8	57.1	120	42.4	29.1	31.8
Production cost	18	20	21.5	17.5	48.5	39	18.4
market perfor-mance	1 480	1 496	1 227	2 091	2 086	1 136	586
Cost for seeds	86	84	93	162	70	161	125
fertilizer	152	116	99	179	193	3	0
herbicide	140	135	74	64	232	104	68
variable cost for machen-ery	160	150	210	193	155	117	133
drying	0	0	0	452	0	0	0
crop hail insurance	10	10	9	9	10	10	10
variable cost	746	718	612	1 324	523	523	444
profit contri-butions	726	778	615	767	612	612	141

Source: Extract from table as cited in Pistrich et al. 2014, 80.

Table 9: Production cost and profit contribution for soybean, grain maize and maize with 30% moisture content in 2011

	soybean	**grain maize**	**maize with 30% moisture content**	
yield level	3	11	14.0	t/ha
price assumption 2011	390	190	121	€/t
Performance main product	**1170**	**2090**	**1689**	**€/ha**
seeds	170	160	160	€/ha
fertilizer	88	336	336	€/ha
plant protection products	105	85	85	€/ha
variable costs for machines	100	140	140	€/ha
harvest- and transportation costs	120	140	140	€/ha
drying costs	20	400	0	€/ha
crop hail insurance	12	15	15	€/ha
other	5	5	5	€/ha
variable costs	620	1281	881	€/ha
Contributions to profit	**550**	**809**	**808**	**€/ha**

Source: Chamber of Agriculture Upper Austria, 2011 (Produktionskosten und Deckungsbeiträge 2011 für Sojabohne, Körnermais und Nassmais).

the context of discussions about tillage systems and no-till systems in particular (see Chapter 3.1.2.4). Evaluating economic bene ts on farm level though is always linked to risk evaluations and needs to include expected yields, prices and input costs such as herbicides, fertilizer, seeds, drying costs (see Table 9),...that are required in order to enable the farmer to produce commodities properly. If however the expected input costs exceed expected output prices, yield gaps are even more dramatic on individual farm level (Seifried 2014, 91 and Uri 2000).

As already mentioned Seifried (2014, 91) conducted a study based upon market performance values. Further results also revealed that cultivating soybean would be more pro table than growing maize if soybean processing industries would be situated within short distances to the production area leading e.g. to low transport costs. Input factors with most impact on output prices are speci c for the type of crop - for soybean production most important factors were prices of herbicides, while for maize fertilizer and drying costs (depending on region and environmental impact) had the strongest in uences. Consequently price uctuations of herbicides and fertilizers impact expected output prices and pro t contributions in varying ways depending strongly on input factors used/required by the crops. Such contributing factors are summarized as *externalities* (Seifried 2014, 91) (positive and negative), which are highly important on farm level, but hard to quantify economically and possibly are only visible after an extensive amount of time[9] (Seifried 2014, 91). Uri (2000) points out that additional (crop speci c) machinery and related inventory would also lead to increasing costs. Therefore an increase in yields does not automatically lead to enhanced net pro ts for the individual farmer. Positive externalities mentioned by Seifried (2014, 91) also include reduced CO_2 emissions, prevention of N leaching, prevention of erosion and susceptibility for pests and diseases which would underline why it is di cult to put a price tag on such *externalities*.

However Seifried (2014, 94f.) prognoses an increasing pro tability of soybean cultivation (decoupled from government subsidies and valorisations) and argues that her results are strongly linked to breeding success, especially in respect to chilling tolerance, lodging resistance and improved early maturity. According to her results the core production areas of soybean would shift and extend into more northern, more chilly regions, because of increasing mean temperatures which would also increase the importance of soybean

[9]The aspect of having to wait for a long period of time to see advantages of actions and decisions (e.g. due to unfavourable effects during the time of transition for instance from one agricultural system into another) is especially true e.g. in respect to conservation-tillage and no-till systems, in which benefits might only sart to show 10 years after implementing (see Chapter 3.1.2.4 on tillage systems) (Uri 2000).

cultivation (see Chapter 3.2). She also stresses the need for more GM-free, nationally produced and organically grown soybeans, as the soybean is bound to start replacing other cultures eventually (Seifried 2014, 94f.).

3.1.2 Crop production

All e orts to either enhance biological nitrogen xation rates (BNF; see Chapter 3.1.2.9.1) or to increase soybean yield include improvements in crop management decisions and measures undertaken in plant production. These decisions, which mostly aim at increasing yields, will then very likely lead to improvements in other (probably less obvious) characteristics of the plant or its environment as well. Such interlinkage as well as trade o s from the plant breeding point of view are discussed in further detail at the end of this chapter (see Chapter 3.1.2.12 on agronomic breeding targets). For example, if agronomic measures such as adapted seedbed preparation for soybean cultivation are performed with the intention of enhancing yields, it may also cause an improvement of physical and chemical soil characteristics, such as the water-holding capacity, leading further to a potentially well established root system and to a more bene cial environment for rhizobacteria, which in turn would increase the possibilities of a successful symbiosis and subsequently enhance the potential of increasing BNF. Furthermore, to stick with the example mentioned above, such an adapted seedbed preparation may also (directly or indirectly) support the potential of enhanced plant health and would ultimately lead to higher potentials in elevated yields (Mechtler 2012 and Soldati 1999, 677f.).

The example given above should illustrate how soybean breeding targets (in this case enhancing yields) are tightly linked to cultivation procedures and interactions between the plant and its environment. In order to understand the connections, this chapter on crop production covers the matter quite thoroughly. It aims to identify basic connections between agronomic crop management decisions and how they a ect (soybean) plants and consequently breeding targets. At the end of this chapter current breeding targets are summarized in further detail. However knowledge about soybean cultivation is vital for their understanding. Secondly in order to identify future outlooks on breeding targets that are aligned with the concept of *sustainability* and coherent with current discussions about probable and possible challenges in the future, rami cations with regards to these (in this chapter agronomic) breeding targets need to be examined critically in a broader setting.

3.1.2.1 Planting dates Planting dates -in combination with temperature and various environmental impact- have major in uence on characteristics such as plant emergence, rapidity of plant development as well as maturity of crops. Especially in cooler environments optimum sowing dates only range within a short time window, which needs to be seized in order to get high yields. The time frame for an optimum seeding date in cooler regions is much shorter compared to warmer locations (Liu et al. 2008).

In the year 1878 Haberlandt (1878, 88f.) oversaw soybean trials and concluded from the gathered results that the most bene cial sowing dates in eastern Austria would be within the rst days of May, but that regions in southern Austrian should consider earlier planting dates. He argued that seedlings hardly showed any sensitive reactions towards light frost events (which might be as low as -2°C (Diepenbrock et al. 1999, 247)) in early springtime (Haberlandt 1878, 88f.). Although Mechtler (2012) states that severe frost events could very likely lead to the death of the seedlings if frost caused damage as deep as underneath the seed leaves.

Another observation worth mentioning is that Haberlandt s recommendations in respect of planting time frames date back more than 130 years, and yet, today s recommendations have barely changed or shifted, but have only become more speci c as understanding and argumentation have improved. Today the recommended time frame for sowing ranges from mid April to the 5^{th} of May (Mechtler 2012 and Pistrich et al. 2014, 56) and this strongly depends on the soil temperature since seed germination is initiated at a soil temperature of 8-10°C (Diepenbrock et al. 1999, 249; Mechtler 2012; Pistrich et al. 2014, 56 and Soldati 1999, 678). To monitor soil temperature measurements should best be conducted in the morning (Soldati 1999, 678).

Sowing dates are strongly related to productivity and also correlated to yield quality. For instance, plants might develop higher yields if sown earlier and grown under favourable conditions (no drought periods, no fusariosis/*Rhizoctonia* or *Diaphorthe sp.*, lack of late frost and absence of delayed emergence). Additionally, if seeds are sown very late in the season, they might not be able to nish ripening or complete their grain lling phase su ciently, and subsequently su er major yield loss (Singh G. et al. 2010, 144f. and Soldati 1999, 678, see also Chapter 3.1.2.12 on agronomic breeding targets).

In Iowa early seeding dates (end of April) are particularly recommended for sites with ideal growing conditions and little biotic and abiotic stress, although across di erent US locations no signi cant improvement in yields were established between late April sowing dates and sowing in second week of May. De Bruin and Pedersen (2008) therefore concluded a relatively wide planting window in the US Midwest of roughly two weeks between the end of April and the beginning of May. During this time frame yield expectations were similar, although earlier planting dates would generally be preferred even though improved yields strongly rely on location-year interactions (De Bruin and Pedersen 2008).

However Murphy and Lemerle (2006) also point out that the sowing time of the crops has major influences on the weed selection and the adaption of the weeds to the life cycle of the crop and the cropping techniques. Early sowing for instance supports a spread of early germinating weed species like giant ragweed (*Ambrosia trifidia*), which is when delayed planting dates could be an option, in order to allow for non-specific herbicide use before sowing (see Chapter 3.1.2.7 on crop rotation and weed management). In addition higher root zone soil temperature, which is lower in the beginning of the growing season and increases with time, is more beneficial for nodulation and nodule function. Later planting dates are consequently more beneficial for a successful symbiosis e.g. with *Bradyrhizobium joponicum* (Zhang et al. 1995 and Dashti et al. 1998).

3.1.2.2 Soil and seedbed preparation Liu et al. (2008) conducted trials in cooler environments in northeastern China and point out that ridge tillage cultivation showed higher root stimulation (see Chapter 2.1.2 on the root system) and improved soybean plant growth compared to flat cultivation. According to the authors these results are linked to the impact of ridge cultivation i.e. to elevated soil temperature as well as to lower water contents.

In Austria harvesting is generally performed close to the soil surface in order to minimize yield loss due to low first pod height (see Chapter 3.1.2.12.10 on lodging resistance). Therefore rock-free arable soil sites are most advisable (Brandstetter et al. 1993, 2f.; Diepenbrock et al. 1999, 248 and Soldati 1999, 677f.). Although generally a fine crumbled, loose and levelled soil layer is most suitable for soybean production (Pistrich et al. 2014, 14 and Soldati 1999, 677f.).

In order to level the plot and for weed management purposes, the field could be towed after it has dried off and harrowed after plant emergence (Brandstetter et al. 1993, 3). In plots with light or medium weight soil types which tend to aggregate, fine crumbled structures should be avoided, and furrows ploughed in springtime instead (Soldati 1999, 678). Plots with heavy soil types on the other hand should be ploughed in autumn using a subsoiler at 15-18 cm followed by soil preparation with a fork rotary tiller. To ensure sufficient nutrient-, water- and soil-air supply, focus should be placed upon avoiding compaction of the topsoil during tillage in springtime (Soldati 1999, 678).

If elds are tilled in autumn, preservation of water soil content was reported to be enhanced further, leading to improved germination conditions in the following spring. Nevertheless reduced tillage with rather deep soil disturbance was also stated to enhance the ability of soybeans to endure osmotic stress (similar results have been observed with phosporus (P) fertilizer applications due to improved root morphology development, which is why P applications were thought of to be justi ed in years with low precipitation rates) (Liu et al. 2008).

The required tillage intensity does not only depend on soil type or the amount of crop residues of preceding crops, but also on the plot speci c weed pressure (Singh G. et al. 2010, 142f.). In soybean cultivation tillage is especially recommended to ensure well aered soil conditions, which are a precondition for successful biological nitrogen xation (BNF; see Chapter 3.1.2.9.1) (Diepenbrock et al. 1999, 248).

However too frequent impact of heavy tilling-machinery on soil, especially under non-ideal weather conditions, may also increase soil compaction. In compacted soil the reduction of nitrate (NO_3^-) leads to a release of atmospheric nitrogen (N_2), as well as to a reduction of N present in the soil. As a result the amount of N required by plants cannot be met, leading not only to a decrease in N-e ciency, but also to the need of additional N fertilizer. All of which is accompanied by decreased soil gas exchange within the compacted soil, which in turn further decreases carbon dioxide (CO_2) gas movement, leading to an accumulation of carbon dioxide in the soil. Ultimately these circumstances could lead to increased CO_2 or CH_4 emission from the soil. These gases would then be released into the atmosphere as greenhouse gas emmissions (Zarea 2010, 206).

This is one aspect why during the past few years *conservation tillage* or *no-tillage systems* have gained in attention. Particularly during the course of the Rio conference (1992), which laid the foundations for a so-called *sustainable agriculture*, an increasing focus on the conservation of soil, water and landscape resources was ascribed (Alletto et al. 2010).

Diepenbrock et al. (1999, 248) and Soldati (1999, 678) however stress that conservation tillage systems should only be considered in most suitable environments.

3.1.2.3 Nitrogen (N)/Carbon (C) balance and how it is influenced by tillage systems Especially since the Rio conference (1992) and the aligned concept of sustainable agriculture, an increasing focus has been directed towards soil quality (Alletto et al. 2010). As established in Chapter 1.1.2, *soil heath* is up to this day considered to be of the utmost importance. Consequently this excursion into the matter aims at identifying what conservation tillage practices entail and what consequences would follow if applied on soybean cultivation in Austria. Ultimately it should support illustrating consequences for agronomic soybean breeding targets in Austria and how they could be aligned with the concept of sustainability.

3.1.2.4 Defining tillage, conventional tillage (CT), reduced or minimum-tillage and no-tillage (NT) or zero-tillage Any mechanical operation performed to create a suitable seedbed on arable soil or on crop residues, in order to optimize conditions for sown seed germination (Alletto et al. 2010), seedling establishment and crop growth (Zarea 2010, 197), can be defined as *tillage* (Alletto et al. 2010 and Zarea 2010, 197). However Zarea (2010, 197) points out that the term *tillage* is a generic concept, which covers a broad variety of meanings. Compared to Alletto et al. (2010), who emphasise mechanical efforts, Zarea (2010, 197) additionally includes weed control using herbicides as well as growth regulators in his notion about *tillage*. Above all he also includes the introduction of fallows with highly competitive cover crops, which should be well managable and sown directly in the mulch layer of the crop residues.

Generally speaking tillage accelerates the decomposition of crop residues (Zarea 2010, 200), supports the control of weeds, loosens and homogenizes the soil (Doyle 2004) and is mostly referred to as *conventional tillage*. According to Zarea (2010, 199), conventional tillage (CT) most commonly indicates a ploughing operation consisting of the use of a mouldboard plough in combination with a disc harrow. But conventional tillage shifted more and more into the focus of criticism, because it was stronger linked to soil erosion, loss of soil structure and loss of organic matter (OM). Furthermore a decline in water infiltration was related to CT systems, which would ultimately pose the threat of reduction in soil fertility and soil quality (Zarea 2010, 199).

In Europe, between 1970 and 1980 and up to the 1990s, efforts were slowly intensified to obstruct dispensable tillage in order to save energy, cost of labour (Alletto et al. 2010; Drinkwater et al. 2000; Doyle 2004 and Zarea 2010, 197f.), cost of fertilizers, pesticides, seeds (Uri 2000), machinery (Uri 2000, and Doyle 2004) and conserve moisture and soil (Alletto et al. 2010 and Zarea 2010, 197f.).

These developments coincided with low prices on agricultural products due to surpluses, which forced farmers to decrease production costs and improve productivity, but it also led to an increased desirability of implementing conservation tillage. Additionally, in the case of highly varying yields, the cost of seed handling and drying would influence costs related to tillage systems, whereas costs related to the production sites are usually assumed to be stable throughout di erent tillage systems (Uri 2000).

Definition of conservation tillage

Uri (2000) refers to a well established de nition of *conservation tillage*, which is o ered by the Conservation Technology Information Center 1996 and embraces a variety of tillage and planting systems that decrease soil erosion caused by water by maintaining at least 30% of the soil surface covered by residues after planting or at least 1122 kg of at, small grain residues per ha^{-1} in order to reduce erosion by wind (Alletto et al. 2010 and Uri 2000).

The quality of the crop residue is also in uenced by the type of crop and the implemented type of tillage performed before planting, as well as the planting method itself (Uri 2000). Besides, a variety of plant production methods can be associated with the term conservation tillage, including minimum, reduced tillage systems and no-till or zero tillage systems (Alletto et al. 2010 and Zarea 2010, 197f.).

Types of tillage systems that fall into the de nition of conservation tillage include rather deep sub-soiling, reduced tillage of 0-15 cm, as well as a variety called *no-surface-tillage*, which is strongly connected to the use of hormonal herbicides. Moreover conservation tillage operations might be quite diverse according to the region and to its speci c requirements in regards to di ering needs between spring and winter crops. For instance, spring crops are frequently sown after ploughing which is rare with winter crops (Alletto et al. 2010).

All these types of conservation tillage are characterised by minimum or reduced tillage methods and follow the approach to distrub the soil as little as possible in order to produce crops. In contrast no-till or zero-tillage operations disturb the soil exclusively on the smallest area possible in order to properly deposit the seeds (Zarea 2010, 197f.).

In regards to sustainable-agriculture, a primary goal of conservation tillage is stated to be the preservation of soil fertility and biodiversity, as well as minimizing negative impact such as erosion, degrading soil structures, or carbon (C) loss during tillage (Boscutti et al. 2014). Moreover conservation tillage also supports the protection of soil organic matter contents (SOM) due to slower decomposition rates of surface residues (which is rooted in less favourable decaying conditions and smaller exposition surface area towards soil-borne micorbes) compared to crop residues which were incorporated in the soil (which would be the case e.g. in conventional tillage systems) (Doyle 2004).

Besides a long list of positive aspects correlated to conservation tillage (which will be discussed in more detail further along, as well as counter arguments), there are some questionable aspects or impact that still remain unknown. For instance environmental in uences of reduced tillage are barely known as yet. This is because the assigned techniques may lead to alterations in soil physicochemical properties and biological activities to a vast extent. Since such shifts tend to be complex and are generally interrelated with each other or have related aspects that remain to be revealed, long-term consequences may be di cult to predict. To illustrate this complexity, Alletto et al. (2010) provide an overview of known connections between tillage and e ects on soil properties and on pesticides in Figure 10.

Positive aspects associated with conservation tillage compared to conservative tillage practices

Positive impact credited to conservation tillage include improved chemical soil properties, such as higher organic matter content (Doyle 2004 and Zarea 2010, 197f.), increased nutrient status, as well as improved physical properties of soil (Zarea 2010, 197f.). Moreover improved soil structure (Boscutti et al. 2014 and Zarea 2010, 197f.), which is characterised through a durable network of macropores (especially bipores), is reported and occasionally even increased macroporosity (especially in soil with substantial earthworm burrows is mentioned (Brady and Weil 1999, 148). In addition increased soil aggregation and aggregate stability are related to conservation tillage systems, as well as improved soil water content (Doyle 2004 and Zarea 2010, 197f.) and enhanced soil biodiversity (Boscutti et al. 2014).

It should be mentioned though, that aimed enhancements such as improved porosity do not always present themselves. Sometimes - especially in poorly internally drained soil - even less pore space was detected under conservation tillage soil regimes compared to conventionally tilled soil (Brady and Weil 1999, 148). Nonetheless, Uri (2000), who performed empirical evaluations with data available from the Cropping Practice Survey conducted by the National Agricultural Statistical Service/Economic Research Service (NASS/ERS) on corn, soybean and wheat during a time period between 1990-1995, particularly stresses the potential of conservation tillage systems in o fering an improved ability to keep precipitation and moisture in the soil during fallow periods or periods of low precipitation. Similar results were published by Zarea (2010, 197f..).

Improved moisture/water holding capacity was linked to increased in ltration rates (Doyle 2004 and Uri 2000), reduced evaporation (Doyle 2004 and Zarea 2010, 197f., 200, 205) and to the expansion of the number of small pores, which was particularly ascribed to no-tillage systems (Zarea 2010, 197f., 200, 205). This characteristic would also allow a reduction of fallows within the cropping cycle and in consequence an intensi cation of the cropping systems (Doyle 2004 and Zarea 2010, 197f., 200).

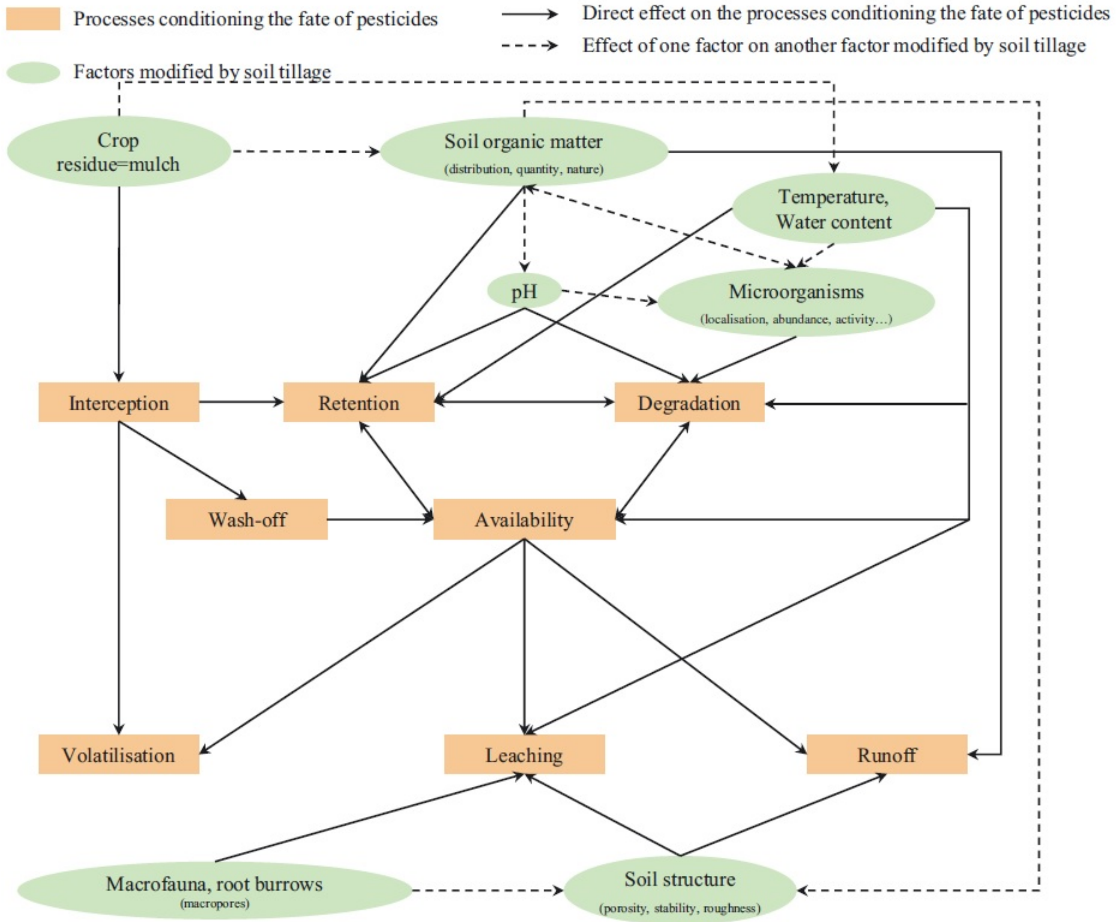

Figure 4. Relationships between the processes conditioning the fate of pesticides in soils, water and air and the soil factors modified by tillage operations.

Figure 10: Connection Tillage and soil e ects and e ects on pesticides

Source: Alletto et al. (2010).

Similarly higher water contents have been reported in systems that implemented conservation techniques compared to conventional tillage systems due to the applied mulch layer (Alletto et al. 2010 and Uri 2000). Through applying this mulch layer a reduction in soil temperature of 1-5 °C near the soil surface may be achieved due to intercepted light energy which is blocked through the mulch layer (Alletto et al. 2010).

Other positive aspects related to an implementation of conservation tillage compared to conventional tillage systems include an increase in sequestration rates of soil carbon (C) (Brady and Weil 1999, 472 and Zarea 2010, 200; 205) and a redistribution of organic carbon within the soil, leading to an accumulation of organic C in soil layers near the soil surface (again, this is a consequence of the mulch layer and the enhanced, yet slower decomposition rate) (Alletto et al. 2010 and Brady and Weil 1999, 148). Slowly decomposing residues (mulch) also create new habitats and may offer additional substrate, which will ultimately attract biota and an accumulation of microbial biomass (Zarea 2010, 200; 205). Consequently, this will lead to an increase in organic C, enhanced N-mineralization and enhanced enzymatic activities (primarily in the upper soil layers) (Zarea 2010, 205).

Nevertheless tillage regimes also effect soil chemical properties, including a modification of soil pH in the top soil layer. For example, reports detected increases, no changes, as well as (most frequently) a decrease in pH in conservation tillage systems, which was linked to an accumulation of soil organic matter (SOM), but also to an aggregation of fertiliser compounds (Alletto et al. 2010).

Furthermore, as Uri (2000) points out, there is the farmer's decision to choose conservation tillage over conventional tillage. The farmer would most likely base his decision upon expectations towards the most economically efficient production system, embedded in his highly individual setting of preconditions. Besides the possibility of basing his choice upon assumptions concerning a raise net farm income, it could also be linked with an expected reduction of risks. In addition Uri (2000) emphasises that elevated yields do not automatically lead to enhanced private net incomes (see Chapter 3.1.1.3 on economic aspects).

However Zarea (2010, 199, 204 ff.) suggests a strong correlation between increased crop yield and no-tillage systems, when compared to reduced tillage systems. This tendency is even more striking when no-till systems are compared to conventional tillage systems. Zarea argues that the N availability in no-till systems would be more beneficial and in addition, less heavy machinery would lead to less soil compaction. And since compacted soil has a variety of disadvantages for plant growth and development, non-compacted soil (which would be promoted through no-till systems) would be characterised through improved nutrient uptake (due to better developed roots in non-compacted soil) and increased soil gas movements (which would enhance microorganism activities). In combination with su cient precipitation rates, all of these proerties would ultimately promote enhanced yields.

Reports about variations in yield potential connected to conservation tillage (in opposition to Zarea, who exclusively refers to no-till systems) have also been published e.g. by Uri (2000), who also linked his ndings to indirect in uences like improving soil structure, organic matter content, microbial populations, improved soil water contents and soil tilth content. At the same time he did not nd signi cant yield increases, but rather variation, which seems to be a commonly found consequence connected to conservation tillage, resulting in higher risks under conservation tillage conditions than under conventional tillage conditions. An explicit explanation seems to be lacking, although factors such as soil features, climate/weather conditions, cropping patterns, pest and disease pressure would all add up to site-speci c tendencies.

Besides Uri (2000) also stresses that it would take as long as roughly 10 years to fully realize the inherent potential of conservation tillage systems and therefore it would also take this period of time to fully materialise the expected enhancement in net farm income e.g. through higher yields. This implies that farmers would have to be able to overcome roughly 10 years of transition, that are stated to be correlated to possible higher risks and lower net farm income.

Also most e ects on soil organic matter (SOM) dynamics should best be measured 10 years after the implementation of the altered (conservation tillage) agricultural management system. Because precise measurements on SOM contents would only o er authentic results after the full potential of the conservation tillage system had unfolded itself (Doyle 2004).

Negative aspects associated with conservation tillage, especially concerning weed control

As stated above, negative aspects related to conservation tillage systems compared to conventional tillage systems include the long time period of roughly 10 years until the conservation tillage regime is able to unfold all of its potential and all of its bene ts. This comes with substantial risks. Moreover one single soil disturbance after initiating the conservation tillage system might already lead to an elimination of any improvements and bene ts related to the altered tillage system (Uri 2000).

Weed control is another major issue in soybean cultivation (see Chapter 3.1.2.8 on competitiveness against weeds). An important strategy to reduce the competitiveness of weeds in a soybean stand is tillage. Hence, effective weed control through tillage is a major task in soybean production (Alletto et al. 2010).

Different tillage systems affect both crops and weed populations in a particular way, because tillage serves as seedbed preparation not only for the crops, but also for weed seeds (Uri 2000). Consequently tillage alters the soil climatic condition which influences dormancy, germination and plant growth of both weeds and crops (Alletto et al. 2010), hence weeds also adapt to tillage systems (a topic encountered in further detail in Chapter 3.1.2.8). Vice versa this means that the composition of weed species found on a certain plot is itself influenced by the tillage system used (Alletto et al. 2010; Boscutti et al. 2014 and Uri 2000). For instance reduced tillage systems would promote annual grasses, volunteer crops and perennial species, which are typically spread through wind (Boscutti et al. 2014 and Zarea 2010, 202f.), such as *Sorghum halepense, Digitaria sanguinalis, Amaranthus retroflexus, and Cardamine hirsuta* (Boscutti et al. 2014), whereas conventional tillage systems would favor broadleafed weed species (Boscutti et al. 2014 and Zarea 2010, 202f.) like *Geranium dissectum, Cerastium brachypetalum, and Convolvuluv arvensis* (Boscutti et al. 2014).

Furthermore conservation tillage systems would mostly contain nutrient demanding weeds (and therefore attract predominantly accompanying Carabid species). In this respect Boscutti et al. 2014 stresses that *sustainability*-effects of agro-ecosystems should be established through species compositions rather than on diversity measures, since (bio-) diversity -even in agro-ecosystems- would be linked to renewal processes and hence productivity and sustainability. Moreover they state that *biodiversity* is gained through a) planned diversity through crop rotations etc. (see Chapter 3.1.2.7 on crop rotation and weed control) and b) so-called *associated biodiversity*, describing the process when species colonize and thrive within agro-ecosystems. These processes would be particularly influenced through soil pH and nutrients, soil organic matter and soil phosphorus contents. The authors concluded that conventional tillage would not significantly affect weed diversity, although there are contradictory studies offering opposite results (e.g. Shrestha et al. 2006, as cited in Boscutti et al. 2014). The authors also emphasise that plant species compositions (as well as carabid compositions) would prove to be a valuable indicator in establishing an ecological condition of a certain tillage system (Boscutti et al. 2014).

The processes of how weed seeds are distributed in the first place include for example mechanical shattering of weed plants and a redistribution of weed seeds throughout different soil layers during tillage. Consequently weed seeds tend to accumulate near the soil surface after having implemented a reduced tillage system. Hence immediately after a conversion from conventional tillage to conservation tillage systems, this incorporation of weed seeds into deeper soil layers is missing and frequently leads to a signi cant increase in germinated, newly produced weed seeds, subsequently requiring an increase in herbicide use (Alletto et al. 2010; Zarea 2010, 202f. and Uri 2000).

As with any herbicide use, it is of the utmost importance to apply the appropriate substances at the right stage of the weed/crop, with suitable weather conditions for an application and to choose a bene cial time of day - which might vary with the herbicide or the crop- and to consider possible plant stress conditions, possible site speci c aspects and side e ects (Uri 2000, see Chapter 3.1.2.8.3 on chemical methods in weed management).

Nonetheless, in the long run (because of the lacking pertuberation of the soil), seeds from deeper soil layers are not brought back to the soil surface through tillage, which leads to a decrease in weed populations over time and a considerable reduction in required herbicide use after the initial time of introducing conservation tillage (Uri 2000 and Zarea 2010, 202f.). However site speci c weed pressure and climate conditions need to be considered, because weed-crop interactions are highly year-speci c (Uri 2000).

In addition, since an increase in needed herbicides is not a mandatory scenario, production costs would not automatically need to be higher/lower or similar in conservation tillage systems when compared to conventional tillage systems (Uri 2000). If, however, increased herbicide and fertilizer use are in order, this would not only enhance input costs, but would also increase threats of groundwater- and surface water contaminations, which is frequently related to no-tillage systems (Drinkwater et al. 2000) and which would ultimately pose the danger of becoming toxic e.g. (but not exclusively) on invertebrates (such as earthworms or arbuscular mycorrhiza fungi) (Zarea 2010, 196).

In respect of the *"[...] fate of applied pesticides* [...] (Alletto et al. 2010) in soil within conservation tillage systems, results are sometimes contradictory concerning dissipation processes (such as retention or degradation) due to a variety of factors involved and the complexity of the interactions, as well as due to a lack of a coherent sampling strategy. Moreover in conservation tillage systems organic matter (OM) content is accumulated in topsoil layers but decreases with depth, leading further to an increase in pesticides in surface soil layers. Although an interception through a mulch layer is thought to be bene cial in this matter, due to its potential in generating photodegradation. In addition crop residues might also restrict the air ow between soil surface and the atmosphere, altering the microclimate and reducing degration through microorganisms (Alletto et al. 2010).

Similar thoughts are reported on herbicides, where up to 70% of their active ingredients may be intercepted through plant residues. Subsequently this interception would lead to a decrease in e ciency, and consequently to a decreased e ciency of conservation tillage (Zarea 2010, 203).

Soil organic matter pools affected by rotation and tillage

In order to establish soil quality (see also Chapter 1.1.2 on soil health), Anyanzwa et al. (2010) suggest an enquiry of soil organic matter (SOM) because it would factor in soil fertility, sustainability and productivity and would be viable even in agricultural systems with poor nutrient status or heavily weathered soil like the tropics.

Two biological processes, which are responsible for controlling SOM inputs and outputs are soil microbial activity and primary plant production. (Anyanzwa et al. 2010; see also Doyle 2004). More speci cally, Brady and Weil (1999, 475f.) additionally list factors such as climate (temperature and rainfall), vegetation and tillage, which all in uence SOM - for instance through impacting the C and N cycle. Furthermore, according to the authors, what is most important concerning the SOM levels, is to preserve a relatively high proportion in the active fraction in oder to guarantee su cient biological metabolism to increase soil tilth and N cycling (Brady and Weil 1999, 481). But SOM turnover is only governed by biotic and abiotic factors (hence ensuring soil fertility), if input and output factors that control SOM turnover are in equilibrium. In regard to in uences on the environment, agricultural practices in uence this equilibrium e.g. through altering carbon sequestration rates. In the best case scenario, soil erosion is limited through crop management techniques and soil biodiversity ensured (Anyanzwa et al. 2010)

Nevertheless there are a lot of studies in which no explicit e ects in SOM or total C and N have been found comparing no-tillage systems with conventional systems (Doyle 2004), even though there have been indications that clay fraction content also plays a vital role in a potential increase in active SOM, modifying microbial activity and in turn microbial metabolites (Doyle 2004 and Zarea 2010, 214). In addition plants use soil organic matter (SOM) as a source for nutrients, so nutrients might be stored and released from SOM and these processes may also be e ected through tillage (Alletto et al. 2010 and Zarea 2010, 212f.). This is also illustrated through changes in SOM composition and advanced humi cation status that may be observed with increasing soil depth ((Alletto et al. 2010)). In comparison microorganisms/decomposers use it as energy-source too (Zarea 2010, 212f.). But if, in contrast, solely total C concentration in soil would be measured *"[...] subtle changes in nutrient status [...]"* (Doyle 2004) would remain undetected (Doyle 2004).

Such positive agricultural management techniques include for example a returning of the crop residues to the eld (mulching) (Anyanzwa et al. 2010 and Brady and Weil 1999, 481f.). In the same way, SOM content may also be in uenced through the removal of crop residues, or the use of fertilizers. Moreover soil aggregate developments have heavy impact on carbon sequestration and -cycling (Anyanzwa et al. 2010). Another example would be to preferably use cover crops rather than bare fallows. The reason is found below and above soil surface, because plant residues constitute important sources of organic matter.

> In addition *"[c]over crops can provide protective cover [e.g. for microbes]and additional organic material for the soil. It is almost always preferable to keep the soil vegetated than to keep it in bare fallow* (Brady and Weil 1999, 481f., see also Chapter 3.1.4.2.2).

Similarly striking for future sustainable, agricultural breeding approaches are potential impact of agricultural systems on terrestrial C and N uxes. Processes related to these complex relationships have come stronger into focus, because understanding them is thought to be crucial with respect to changes in atmospheric chemistry and climate change. Hence decomposition processes and an increase in SOM impact how the atmosphere is constituted, for example carbon content stored in SOM is not be released as CO_2 to the atmosphere. Consequently a decrease in SOM is accompanied by an increase in atmospheric CO_2 (Brady and Weil 1999, 481f.).

It is also important to see that cultivation of soil results in a reduction of SOM, because organic C is oxidated quicker through higher soil aeration and a greater surface area of SOM which is exposed to microbial mineralization (Doyle 2004). Nonetheless, as just established, cultivation is still more preferable than fallow (Brady and Weil 1999, 481f.).

For example, in conventional tillage systems, rapid mineralization is more frequently observed as are potential loss of C and N from the soil, when compared to conservation tillage systems (Anyanzwa et al. 2010). Therefore tillage is also stated to be a primary factor in decreasing the number and the stability of soil aggregates, leading to organic matter depletion (Anyanzwa et al. 2010 and Doyle 2004). In other words tillage leads to a decrease in SOM, but before that particulate organic matter (POM) is lost more readily (Anyanzwa et al. 2010).

As mentioned before higher SOM quality is also attributed to higher microbial activity, but more speci cally bacteria are predominantly found in conventional tillage systems, whereas fungi are predominantly found in conservation tillage systems (Doyle 2004).

Apparently tillage may alter sporulation of some species of arbuscular mycorrhizal fungi (AMF), which was observed more frequently in no-tillage systems soil samples compared to soil samples from conventionally tilled plots. Still the experiments conducted by Jansa et al. (2002) revealed that diversity of AMF species signi cantly depended on the trap plants used, even though it is a commonly (and scienti cally sound) method which is widely used (also because of the relatively low costs). Their results also showed that the tillage system itself was of less importance compared to the signi cant in uence of the cropping cycle and particularly to the previous crop that was grown directly before the soybean (Jansa et al. 2002).

A short introduction of the greenhouse gases atmospheric carbon dioxide (CO_2) and methane (CH_4)

Carbon dioxide (CO_2) belongs to the ve primary greenhouse gases present in the earth s atmosphere. CO_2 allows short-wavelength solar radition to enter but prevents a great amount of the longewave solar radiation from getting out again (Brady and Weil 1999, 482f.). The concentration of CO_2 in the atmosphere was reported to be 390 mmol mol^{-1}in 2012 (Lam et al. 2012) (in comparison, in the year 1800 it was stated to be 280 mmol mol^{-1} (Lam et al. 2012 and Taub et al. 2008) and is prognosed to rise up to 550 mmol mol^{-1} in 2050 (Lam et al. 2012), and about 540-958 mmol mol^{-1} in the year 2100 (IPCC, 2001, as cited in Taub et al. 2008). This results in an enhancement of about 30% since the pre-industrial times (Morgan et al. 2003). Consequently this leads to constantly rising temperatures, which in turn impact the global climate (including in uences on rainfall distribution patterns) and subsequently the length of the growing season and the sea level (Brady and Weil 1999, 482f.).

Since many biological processes are located within the soil, and since those processes account for about half of the gases which are released into the atmosphere, soil and tillage systems play a major role in developments correlated with global climate change. For instance, a great share of atmospheric CO_2 originates in net loss of organic matter from the soil. Cloud cover or vulcanic dust on the other hand may balance out some of these e ects. This list of complex interlinked impact factors illustrates how predictions about realistic future developments on global climate are complex and di cult to establish (Brady and Weil 1999, 482f.).

Another greenhouse gas is methane (CH_4) which makes up a much smaller percentage of the atmospheric gas composition, but is 30 times more e ective in preventing long-wavelength radiation from leaving the atmosphere again and is consequently more e ective in attributing on global temperature elevation. All three greenhouse gases methane, carbon dioxide (CO_2) and nitrous oxide (N_2O [10]) originate from (poorly aerated) soil. Soil hence serves as a source and a sink in regards to agriculturally managed soil systems (Brady and Weil 1999, 485).

Especially the widely distributed and commonly used nitrogen fertilizers (particularly ones consisting of inorganic ammonium), which have been used in agricultural systems over long periods of time, seem to reduce the ability of the soil to oxidise, e.g. methane, through reducing certain types of bacteria. These kinds of bacteria use the enzyme methane monooxygenase to generate energy from methane, thereby breaking up methane and preventing it from being released as a greenhouse gas into the atmosphere (Brady and Weil 1999, 485).

In other words, the composition of soil bacteria seems to be altered through rapidly available ammonium brought to the elds through certain kinds of fertilizers, leading to a shift in the composition of bacteria towards an increase in ammonium-oxidizing bacteria at the cost of methane-oxidizing ones. If elds are fertilized with manure on the other hand, results of studies suggest that there is no such shift and soil bacteria capable of methane-oxidation remain present (Brady and Weil 1999, 485).

This short introduction of greenhouse gases illustrates how soil management and the choice of fertilizers are important contributing factors in greenhouse gas control (Brady and Weil 1999, 485) (see also Chapter 1.1.2 on soil health).

How CO_2 is linked to conservation tillage and climate change

Critical voices often state that conservation- and particularly no- tillage systems would cause higher xed investment costs (due to higher chemical expenses) and higher on-farm risks e.g. by uctuating incomes or lower yields compared to conventional tillage systems (Manley et al. 2005). Furthermore it seems to be widely accepted that a transition from conventional to no-tillage system does lead to an increase in soil carbon (Manley et al. 2005. and Tan et al. 2007). Calculations on fossil fuel use however demonstrated that bene ts of no-till systems could be overstated and that advantages from CO_2 savings were counterbalanced by N_2O emissions (Manley et al. 2005).

Generally speaking conservation tillage practices, as well as other management practices such as fertilization, cropping and applying manure, have originally been intended to prevent soil erosion (Doyle 2004 and Manley et al. 2005) and increase crop yields (Doyle 2004). A focus on soil organic matter content (SOM) (Doyle 2004) and soil organic carbon

[10]Nitrous oxide (N_2O) is another greenhouse gas, which is originating e.g. from microorganisms in poorly aered soil, though it is not directly involved with the carbon-cycle, but with the N-cycle (Brady and Weil 1999, 485). Further details on the N-cycle are given in Chapter 3.1.2.9 on N fertilizer use.

(SOC) sequestration (Manley et al. 2005) were therefore added to research agenda at a later date.

It should therefore be noted that organic carbon not only plays a valuable role in soil quality or crop productivity, but that it might also be considered to be a carbon sink for sequestering atmospheric CO_2 (Zarea 2010, 213). Hence, sequestering organic carbon in cultivated land poses the potential (Manley et al. 2005) to deal with the greenhouse gas carbon dioxide, which also plays a major role in climate change (Brady and Weil 1999, 482).

For instance Lal et al. (1998, as cited in Manley et al. 2005) estimated that alterations in plant production practices on a global level could sequester over 200 million metric tons of organic carbon every year. According to Manley et al. (2005), the Intergovernmental Panel on Climate Change (IPCC, 2000) presented gures demonstrating an organic carbon sequestration rate of soil managed with conservation tillage of one ton C per year, whereas other magnitudes provided by Uri (2001) and Follett (2001) (both as cited in Manley et al. 2005) ranged between 3 to 500 kg C ha-1 yr-1.

The immense potential ascribed to agricultural management practices to impact carbon sequestration and hence climate change is further illustrated by Canada announcing the e ort to meet 5 % of its Kyoto goal in 2005 through altering agricultural practices (Manley et al. 2005).

What might be noteworthy, is that IPCC et al. (2014, 127) did mention agricultural management practices in respect to factors in uencing carbon sequestration in soil, but that in the 2014 report additional emphasis was placed upon a orestation.

However a closer look at the relationship between atmospheric carbon dioxide and conservation tillage systems seems to be in order, especially given the circumstances that the reactions of soybeans towards elevated atmospheric CO_2 levels are considered to be highly interesting in current research on climate change scenarios and discussions on food security (see subsequent Section and Chapter 3.1.4.2.2 on food security).

Discussions concerning di erent conservation tillage systems are quite heated though, as they o er contradictory results. For example, as already mentioned, it seems to be commonly accepted that soil carbon does increase if a no-till system is implemented subsequent to a conventional tillage system (Manley et al. 2005 and Tan et al. 2007). Nevertheless studies showed that no-tillage systems do not necessarily lead to C sequestration within the rst 20 cm of soil. Modi cation simulations of total SOC stock during such a transition for instance suggest that slow carbon emissions would be reduced and that a transformation in the tillage regime (conventional to no-till) would have less impact on the SOC level, but would rather lead to an increase in the ability of reducing C release by building up a higher baseline SOC content (Manley et al. 2005 and Tan et al. 2007). In addition it was stated that with increasing soil depth, the di erences between conventional tillage systems and no-tillage systems concerning soil organic C would align, with some researchers proposing that C is primarily di erently distributed, but no real enhancement in C sequestration would take place. Consequently, signi cant di erences in soil organic C between tillage systems have only been found in the top 5-15cm, which only sometimes was succeeded by an opposite trend in soil depths more than 15 cm. (Manley et al. 2005 and Tan et al. 2007).

Thus microbial decomposition is also supported by tillage/ploughing practices since they aerate the soil and help break up organic residues, consequently providing enhanced accessibility and use of residues for the microbes (Brady and Weil 1999, 476). Such measures as ploughing are agreed to enhance CO_2 release. Simultaneously though, conventional tillage practices seemingly support adsorption and stabilizing increased SOM levels (possibly through enhanced contact with sorption sites such as Fe and Al hydrous oxides) (Manley et al. 2005). Whether the soil organic matter (SOM) content enhances or declines depends on whether or not carbon is lost or gained. An increase in carbon is predominantly achieved through plant residues or applied organic substances, whereas decrease in carbon mainly results from respiration (CO_2 loss), removal of plants or plant residues or erosion. (Brady and Weil 1999, 472) Processes that support adsorption and stabilizing increased SOM levels were only considered to besuccessful if plant residues would remain on soil layers near the soil surface. Even though the complexity of processes through which conventional tillage systems might be able to store even higher rates of carbon compared to no tillage systems remain largely unclear (Manley et al. 2005).

Management practices in agricultural systems should therefore aim to a) enhance additional organic carbon to the soil through increased crop production or growing cover crops during the winter and/or b) reduce C loss through reduction of soil erosion and implementation of conservation tillage (Brady and Weil 1999, 472).

In addition soil organic matter (SOM) has a very slow turnover rate. Short term e ects are frequently established through an assessment of particulate organic matter (POM) or through biologically active fragments of SOM such as enzyme activities and microbial biomass (Zarea 2010, 216f.). In order to measure soil organic carbon degradation, Zarea (2010, 214;217) proposed use of microbial biomass or microbial community assessments as indicators, since this approach would allow to detect changes rapidly due to the microbial turnover rate of less than a year. Moreover minimum tillage systems are also said to lead to increased microbial biomass in the topsoil layer. Although enzyme activity would also strongly depend on the season in which samples are collected and would additionally be strongly related to site speci c soil properties.

In addition to soil systems and microbes, as just established, plants also respond to elevated carbon dioxide levels. Amongst these plant reactions particular responses have been reported in symbiotic N_2- xing legumes such as soybeans (Lam et al. 2012).

Effects of elevated atmospheric CO_2 concentrations on plants

Soybean s response to a carbon-rich atmosphere has been most thoroughly studied, moreover soybean has risen in popularity as a model crop or key indicator for estimating reactions of (agro-)ecosystems to elevated carbon dioxide levels in studies concentrating on plant responses to elevated CO_2 (Jablonski et al. 2002 and Taub et al. 2008). Especially yield responses and seed N concentrations of soybean in elevated CO_2-conditions are of major interest (Ainsworth et al. 2002; Jablonski et al. 2002 and Taub et al. 2008).

Amongst other food crop species N_2- xing legumes (see Chapter 3.1.2.9.1 on BNF) stand out not only because they are thought of as being crucial for carbon sequestration, but mainly because they are believed to be capable of enhanced xation rates under enhanced CO_2 concentration, subsequently leading to increased nodule size, nodule number per plant, as well as enhanced nitrogenase activity of particular kinds (Lam et al. 2012) without loss in seed N (Jablonski et al. 2002). Therefore Lam et al. (2012) suggest that N_2- xation ability should act as a referee trait in selecting highly adapted cultivars for CO_2-enriched conditions.

In addition to the alterations just mentioned (nodule size/number and nitrogenase activity), Ainsworth et al. (2002), who conducted a meta-analysis on soybean experiments issued between 1980 and 2000, focused on two trends which are commonly discussed when referred to soybeans cultivated under elevated CO_2 conditions:

- Findings of Ainsworth et al. (2002) supported the general opinion that soybean - if confronted with elevated CO_2 growing conditions - would respond with a greater acclimation of photosynthesis, either due to insu cient N availability or due to genetic restrictions in generating extra N sinks. Results suggested that nodulating soybeans are able to x atmospheric N_2 biologically in N restricted environments (see Chapter 3.1.2.9.1 on BNF), but that this process would cost a lot of energy (carbon). In contrast to non-nodulating genotypes, nodulating genotypes would possess the ability to access new/additional sinks for carbohydrates through the symbiosis with rhizobacteria. Therefore, within CO_2 enriched environments, photosynthetic acclimation of nodulating genotypes is predicted to be very small. Non-nodulating genotypes on the other hand would be expected to show high photosynthetic acclimation (Ainsworth et al. 2002).

However, since the drop in available N was lower in N- xing legumes compared to cereals (Ainsworth et al. 2002, see also McNeil 2010), this would indicate the possibility of enhanced nitrate use rather than enhanced xation rates. In addition elevated CO_2 concentration is not always reported to go along with a down-regulation of photosynthetic capacity (Nakamura et al. 1999).

However, especially in relation to endured osmotic stress, increased rates in photosynthesis were reported on N- xing legumes due to extra carbohydrate sources (nodules) (Ainsworth et al. 2002 and McNeil 2010, 338f.). Moreover Ainsworth et al. (2002) stated that CO_2 assimilation rates in soybeans grown at elevated carbon dioxide concentrations were enhanced by 39% compared to controls, even though stomatal conductance was reduced (40%) as was RUBISCO activity (11%), leading further to considerable reduction in canopy photosynthetic rate (59%) and enhanced leaf area (see Chapter 3.1.2.12 on agronomic breeding targets), while (carbon containing) carbohydrates would be expected to increase (Ainsworth et al. 2002; Jablonski et al. 2002 and Taub et al. 2008). Ainsworth et al. (2002) further construed a decrease in the photosynthetic rate in situations of limited N but not otherwise. In addition they did not detect a shift in the root:shoot ratio in CO_2 enriched environments. Therefore Ainsworth et al. (2002) were able to demonstrate how non-nodulating soybean varieties proved to have greater leaf nitrogen contents compared to nodulating genotypes. This again leads to the conclusion that elevated CO_2 concentrations lead to a decline in N content within plants that experience restrictions of N. Another e ect is a decline in seed protein content (see Chapter 3.1.3.2, on high seed protein content).

- It is believed that soybean seed yield response (if grown in enhanced CO_2 concentrations) is lower than the response of total biomass, but in the review of the literature results are inconsistent (Ainsworth et al. 2002). Also responses to rising atmospheric CO_2 concentrations vary according to crop species and include alterations in mass, number and quality parameters such as nutrient concentrations in seeds (Jablonski et al. 2002). For example cultivation of soybean and rice under enhanced CO_2 concentrations lead to no signi cant decrease in seed N, opposed to wheat and barley (Ainsworth et al. 2002 and Jablonski et al. 2002). Kimball (1983, as cited in Jablonski et al. 2002) states an average yield increase of 37% of 37 agricultural species and more speci cally a rise of 23% for fruit crops, a plus of 31% for C 3 grains, and an increase of 31% for legume seed, as well as an enhancement of 12% for ower crops.

In soybean (leaf) tissue on the other hand elevated concentrations of carbon dioxide lead to reduced nitrogen and phosphorus concentrations (as well as reduced concentrations of other micronutrients). Similarly the constitution of macronutrients has been reported to be altered. So not only are the nutrient concentrations responding to elevated CO_2, but the composition of macronutrients re ects this environmental impact as well. For example if leaf CO_2 uptake was enhanced this resulted in a decrease in nitrogen and sulphur containing protein contents (Ainsworth et al. 2002; Jablonski et al. 2002; Nakamura et al. 1999 and Taub et al. 2008). Although the multitude of mechanisms leading to reduced N and decreased protein concentrations within enhanced carbon dioxide environments are not quite understood, one of the reasons for reduced N and protein concentrations was stated to be caused by dilution evoked by enhanced accumulation of non-structural carbohydrates (Taub et al. 2008). According to Ainsworth et al. (2002) the cause is to be found in the genetic constitutions of soybean cultivars as well as in enhanced assimilation rates. These are in turn rooted in increased leaf areas and total dry weight and would then decline throughout time. This process is accompanied by a reduction of carbon required by reproductive organs (sinks) as well as a considerable drop in the Harvest Index (which would have been expected under elevated CO_2 growing conditions).

> Except that *"[t]his failure of seed yield increase to reflect the potential provided by increased canopy CO2 uptake suggests there is considerable scope for improving soybean for the elevated CO2 atmosphere developing over this century* (Ainsworth et al. 2002).

Also reports about decline in HI as a reaction to elevated CO_2 concentrations are inconsistent throughout studies (see e.g. Liu et al. 2005) and believed to be unspeci c to cultivars, maturity group or environments. Apperently though this drop in HI appears to be rather characteristic to soybean. Ainsworth et al. (2002) hence stated a rather alarming notion of modern cultivars probably lacking in adequate adaption to CO_2 elevated environments.

Shifts within the composition of our atmosphere are therefore re ected in the constitution of seeds (Ainsworth et al. 2002), which furthermore has impact not only on insect herbivores but possibly on human nutrition as well (Taub et al. 2008). In addition changes in the composition of seeds also lead to alterations in reproductive rates of plants (Jablonski et al. 2002). Moreover results of the meta-analysis conducted by Ainsworth et al. (2002) revealed that the energy soybean invests into it s reproductive organs was a great deal less compared to energy levels put into photosynthesis and total plant production. This means that there are obviously numerous plant feedbacks restraining further energy being put into reproductive traits (e.g. yield), which is particularly interesting since soybean serves as a model crop that has been *"[...] artificially selected to maximise investment in seed* [...] (Ainsworth et al. 2002). This further concludes that carbon uptake on a whole-plant level needs to be considered (Ainsworth et al. 2002). Jablonski et al. (2002) additionally point out that plant responses to enhanced CO_2 concentrations during the vegetative stage are not consistently linked to those of reproductive-organs and that plant responses may change throughout its life-cylce.

Role and effects of ozone (O_3)

Oxidised nitrogen (NO_x) and in further consequence ozone, which is formed when sunlight hits NO_xwhile being accompanied by hydrocarbons, has risen 1 2% in countries in the northern hemisphere. This indicates that ozon concentrations are increasing even faster than atmospheric CO_2 concentrations. But ozone may be formed far away from pollution sources. Furthermore it has been stated that during mid-summer almost 25% of the global surface encounters threats of tropospheric ozone in excess of 60 parts per billion (Morgan et al. 2003).

In the case of ozone soybean may serve as model plant for possible future scenarios, because it is very susceptible even to low degrees of O_3 exposure (even though variation among cultivars is rather large). Generally speaking there are two types of ozone exposure I) short term/acute with 120 particles per billion and II) chronic. Both types, as well as their consequences for plants, may be illustrated in further detail: For instance chronic exposure, even at low concentrations such as 40 60 parts per billion, may lead to yield loss up to 10%, or (depending on the concentration) even up to more notable loss in leaf green area/biomass (in soybean up to 80%). Chronic exposure would consequently cause carbon limitation and further altered seed yields, although results were reported to be contradictory (Morgan et al. 2003).

Damage was also reported to increase in a linear way once a particular threshold is exceeded. Except of course if ozone exporsure takes place in an acute form, which is stated to occur only in few places in the world, but in which case photosynthesis would be decreased, followed by cell death and the formation of necrotic tissue. Besides visible necrotic leisures, soybean plants with chronic ozone damage often show restricted growth and reduced dry mass, subsequently leading to reduced pod production and hence lower yields. In addition seeds have been reported to have lower seed weight compared to controls (Morgan et al. 2003).

Consequences from enhanced ozone concentrations on the atmosphere and climate responses also include impact on UV-B radiation, alterations on leaf-air/water vapoour pressure and enhanced temperatures. However since CO_2 and O_3 uptake from plants are negatively correlated, increased CO_2 concentrations would generally cause suppressed uptake of elevated ozone due to a decrease in stomatal conductance (Morgan et al. 2003).

3.1.2.4.1 Reduced tillage, mixed-cropping/intercropping and fallows Traditional crop stands in Austrian agricultural production systems are composed of one single cultivar which is grown on the whole plot. However there are possibilities to grow more than one crop species side by side which is then called mixed- or intercropping system. These alternative techniques could be used e.g. to enhance the biodiversity within the agricultural system, improve the use of resources (like water, nutrients, light and vegetation period), enhance yield stability and lodging resistance, reduce biotic and abiotic stresses and to improve the nutrient uptake of all crops involved (Honermeier 2006, 10). It should be noted though that intercropping systems are highly complex, as interactions need to be considered on a whole-system level, and that research on mixed-cropping stands with soybean in Austria is still in its infancy. Fustec et al. (2010) for example point out how roots from di erent species, involving legumes as well as non-legumes, interact. Friedel et al. (2003) states how intercropping in uences the biological nitrogen xation (BNF) rates, with best results measured with 80% legume and 20% non-legumes in an intercropping system[11]. Cooper and Scherer (2012, 406) on the other hand highlight possibilities of connections between roots of di erent species through a network of arbuscular myc-

[11]If in an intercropping system, consisting of legumes and non-legumes, the legumes would constitute the greater share the legumes would tend to show less variation in BNF rates, as well as higher values in fixed N compared to a legume monoculture. This is correlated with the nitrogen uptake by non-legumes, which are incorporated as partner crop in an intercropping system, because they take up the mineral N from the soil. By doing this, they prevent mineral N in the soil from suppressing BNF in legumes. Furthermore, such an association of plants might even lead to higher symbiotic nitrogen fixation rates (Cooper and Scherer 2012, 406).

orrhiza, pointing out the potential of direct transfer of small amounts of N through the hyphaes. According to Vollmann et al. (2010) on the other hand, intercropping also affects seed quality parameters (see also Chapter 3.1.2.8 on competitiveness against weeds). In any case, it gets clear how a large variety of interconnected factors contributing in intercropping systems, turning it into a highly complex system.

However a planned increase of biodiversity is tightly linked to the term *planned agro-biodiversity* which aims at improving the diversity in farming systems, achieved through intentionally established methods such as smart crop rotations or the introduction of cover crops in order to enhance soil fertility or weed suppression. It also aims at reducing the susceptibility of crop stands to diseases while improving the accumulation of bene cial organisms within the plot. All of these measures seek to improve the crop performance and simultaneously try to decrease external input levels (Báberi 2013, 7).

In systems in which ploughing is used, recommendations include the use chisel plough with soybeans e.g. in combination with barley cropping, because a mouldboard plough would lead to an increased seedbank in the soil. This would be especially problematic if the frequency of ploughing would be rather high (Zarea 2010, 203). In no-tillage systems on the other hand an accumulation of weed seeds near the surface was observed. A mere reduction of tillage could consequently be more desirable in some cases, e.g. if a larger share of crops within the cropping cycle or the plots are particularly susceptible to high weed infestations. What should also be considered is that the interval of performed tillage also serves as selection criterion for weeds. For instance high frequency in tillage enhances the likelihood of higher infestation rates with annual weed species (Murphy and Lemerle 2006).

An example of an intercropping system which is currently gaining in attention is the combination of soybean and forage rye. Experiments on this combination have been overseen and evaluated by the *Boden.Wasser.Schutz.Beratung (BWSB)* in Upper Austria[12] and results showed considerable bene ts in respect of this intercropping combination as well as on the speci cs of the technique used. Groundcover prevents erosion, as would the use of no-tillage systems (see also Brandstetter et al. (1993, 3)). But due to the introduction of forage rye, weed suppression in the soybean stands is targeted as well, as forage rye (when planted e.g. in early August, thus allowing for early sowing of soybean) is assumed to be able to close the canopy quickly enough to prevent high weed infestation.

[12] For further information in respect to barley-soybean intercropping in german language see *Direktsaat- und Untersaatenversuche der Boden.Wasser.Schutz.Beratung*, BWSB, Boden Wasser Schutz Beartung and Schütz, Robert (2014): Direktsaat und Untersaatversuche. In: Der Bauer 9. April 2014.

Further rye is thought ideal in efficiently using N, creating allellopathy and consequently depriving weeds from UV radiation and nutrients (Schütz 2014).

At a certain stage (before emergence of soybean) forage rye gets either flattened or cropped above soil surface, forming a mulch layer for soybean, which is sown directly into the mulch layer. 30-40 days after soybean sowing, an additional cropping of the rye would be an option in Upper Austrian environments. For low input/organic farming systems such procedures are also mentioned to be highly attractive, because other mechanical tilling methods would be obsolete (Schütz 2014).

According to BWSB, preconditions which are considered to be unsuitable for a soybean-forage rye combinations are heavy, cool soil types which tend to stagnant moisture. Moreover, year-interactions are reported to have major influences on the intercropping combinations. Previous experiments (n=4 farms) have achieved seed yields up to 3000kg/ha, although 2014 soybean seeding dates were late in the Upper Austrian trial farms and resulted in 1300kg/ha seed yield on average. However in Upper Austria intercropping systems are still in its infancy and trials pointed out how these systems are significantly related with year-interactions and still pose elevated risk of considerable yield loss in years with drought. Therefore it will take more time and efforts to develop mixed cropping systems that will be suitable for large-scale implementation (Schütz 2014).

A completely different approach is provided by Murphy and Lemerle (2006) who highlight beneficial effects of fallows and annual or perennial pastures as addition within the cropping sequences. Such interruptions combined with completely different management practices may have a huge influence on the weed selection as they disturb the growing conditions the weeds have adapted to. However Brady and Weil (1999, 481f.) and Zarea (2010, 213f.) highlight that fallows are less profitable than growing crops as they won't add to the net farm benefits. Current debates on food security (see Chapter 3.1.4.2.2 on food security), also might lead to the conclusion that fallows might not be seen as the most suitable approaches. In addition cover crops and vegetated soil types are stated to be more preferable than bare fallows in most cases (Brady and Weil 1999, 481f. and Zarea 2010, 213f.).

Reported disadvantages related to soybeans used in intercropping systems in combination with the use of smother crops include a decrease in soybean yields when compared to controls or rotation cropping systems[13]. Reasons that were associated to the decrease in soybean seed yield included competition over light and nutrients between crops and

[13] Rotation cropping systems are not that often found in the USA but may be regarded as traditional cropping system in Austria.

smother crops (Anyanzwa et al. 2010; Vollmann et al. 2010 and Zarea 2010, 203). Soybean trials with mixed cropping stands were also conducted with mustard and small grain cover crops like wheat (*Triticum aestivum L.*), winter rye (*Secale cereale L.*) or hairy vetch. A main aspect in chosing a suitable cover crop is the ability of eliminating them in order to keep the competitive strength to a minimum (Drinkwater et al. 2000 and Zarea 2010, 203).

However, as already pointed out, in Austria such undertakings are still very much in their infancy, but should be targeted more thoroghly in research, as they provide a lot of advantages (additional yields, decreased weed pressure, improved yield stability, less lodging in soybean, favourable use of resources and prevention of soil erosion, amongst many others). Still in order to make them large-scale applicable, these systems need to become more cost efficient, suitable intercropping partners need to be established and the significant yield-year interaction needs to be understood in order to decrease the risk of significant yield loss.

3.1.2.5 Seeding rate and crop management Soybeans belong to the group of epigeous germinating plants meaning that the bent hypocotyl reaches soil surface first and cotyledons are pulled up afterwards (Kumundi 2010, 52f.; Mechtler 2012; Olechowski and Upfold n.d. and Soldati 1999, 678). It is for this reason that the planting depth should be relatively shallow. Would the sowing depth be chosen too deep - especially in combination with encrusted soil surface (e.g. due to aggradation) - this could lead to insufficient strength of the hypocotyl to burst through soil surface. Consequently a handicapped emergence would, in the best case scenario, lead to disadvantages in respect to weed pressure for soybean seedlings, or, in the worst case, to no emergence and therfore no plants/yields at all (Soldati 1999, 678).

Recommended planting depths vary slightly depending on the literature consulted and are suggested to range between 3-4 cm (Mechtler 2012), 3-5 cm (Diepenbrock et al. 1999, 249), 2.5-3.7 cm (Singh G. et al. 2010, 146f.), or 2-3 cm (Soldati 1999, 678).

If the seeding date coincides with cool and wet soil conditions emergence can be delayed (De Bruin and Pedersen 2008). Sowing under dry weather conditions could be beneficial for the soil structure (less compaction due to heavy machinery), but could also lead to insufficient moisture for the seeds and hence delayed emergence (Mechtler 2012). It is therefore recommended to choose a slightly deeper sowing depth of about 5 cm when sown under dry weather conditions or in soil with low water-holding capacity in order to use the available soil moisture (LK OÖ and LK NÖ 2010, 10).

The most suitable seeding rate for early ripening 000/0000-maturity group varieties ranges between 70-90 germinable seeds per sqm (Brandstetter et al. 1993, 3; Diepenbrock et al. 1999, 249 and Mechtler 2012), or rather 50-70 plants per sqm after emergence (Mechtler 2012 and Pistrich et al. 2014, 56). 00-varieties should be planted in less dense populations with 50-80 germinable seeds per sqm, or 60 plants per sqm after emergence (Brandstetter et al. 1993, 3; Mechtler 2012 and Soldati 1999, 678). This reduced plant population density in 00-varieties is recommended because these varieties have higher plasticity due to the ability of building lateral shoots including pods (Brandstetter et al. 1993, 3). In addition a 10% reduced seeding rate should be aspired in more moist climates (Soldati 1999, 678). Denser soybean stands of 000-varieties are said to have higher rst pod hights subsequently leading to reduced loss during harvest (Mechtler 2012; Pistrich et al. 2014, 56; Soldati 1999, 678 and Uri 2000). At the same time more densely planted soybean stands may also show increasing tendencies towards lodging (see Chapter 3.1.2.12.10 on lodging-resistance) as well as reduced ripening (Soldati 1999, 678). Further damage may be caused by birds who are reported to frequently reduce the number of seedlings (Soldati 1999, 678). Since thousand seed weight is highly dependent on the cultivar and could range between 160 g to 240g, the required seeding rate is speci c for each cultivar. Therefore seeding rate should be calculated using the speci c thousand seed weight of the cultivar (Soldati 1999, 678):

$$Seed\,rate\,(kg/ha) = \frac{desired\,plant\,number\,per\,sqm\,x\,thousand-seed-weight\,(g)}{germination\,(\%)}$$

Suitable sowing terchniques include single seed and seed drilling methods. Generally though single seed planting systems are to be preferred (Diepenbrock et al. 1999, 249 and Soldati 1999, 678) because of a more even plant spacing which is said to lead to improved emergence and would encourage a more even ripening of the soybean stands, as well as enhanced competitiveness against weeds (Mishra 2010, 214 and Soldati 1999, 678). If a single seed sowing machine is available it should be equipped with a soybean/beet sowing coulter. Furthermore a slow driving speed of 3-6 km/h (1.86 to 3.73 mph) should be aimed for (Soldati 1999, 678).

In regards to response to planting dates and seeding rates in northern climates of the US, reports suggest that the harvest dates were not in uenced by the planting dates. Besides, increased yield was reported if the seeding date was one to two weeks earlier than traditionally used planting dates (early May in Midwest/Iowa). De Bruin and Pedersen (2008) also suggest that an optimum seeding rate would be less than current suggestions for most locations in the US. O cial recommendations in Iowa advise to enhance the seeding rate if the seeding date is later in the season, even though there was insu cient evidence found in the study results that would support such recommendations. But results did show that reduced seeding rates entail elevated risks, but since increased seeding rate leads to enhanced cost, the conclusion was to rather focus on improved economic efficiency than on yield maximization (De Bruin and Pedersen 2008).

Furthermore seeding density also influences the biomass production and the time of canopy closure. In addition, Liu et al. (2008) point out that colder cropping locations (2-3 degrees latitude equivalent to a drop of 3-4°C average temperature) would need higher seeding rates (an additional 40 to 50 plants per sq m), which is the case in northeast China, resulting in a total of approximately 200-300 plants per sq m in these locations. The reason originates in lower total biomass accumulation and smaller plant growth of cultivars when grown in cooler environments. This means that enhanced plant density is required in order to reach maximum light interception and enhanced yields in cooler environments (Liu et al. 2008).

3.1.2.6 Row distances The spatial arrangements and planting patterns have an impact on the crop canopy structure. For example certain crops or genotypes show more plasticity than others in altering their canopy architecture; hence there are differences in weed suppressive ability according to the ability in branching and shading the soil (Mishra 2010, 214f.).

Rapid emergence and early shading of the row middle spaces contribute to reducing weed competition. If the row spacing is narrower the canopy could close at an earlier plant developmental stage thus reducing light reaching the ground and making it more difficult for weeds to emerge. A closed canopy would also change the microclimate by altering the light intensity, temperature and evaporation at the soil surface. A homogenous plant distribution with relatively uniform plants may also contribute to a better use of resources and to strengthening crops, thus supporting their competitive ability against weeds (Mishra 2010, 214f.).

In Austria recommended row spaces range between 15 and 40 cm (Mechtler 2012 and Soldati 1999, 678) even though in Burgenland row distances up to 0.75 meters can be found in organic production systems. The reason is to be found in the use of shared machinery for both maize and soybean production.

A positive aspect related to narrow row spacing includes decreased soil erosion which could be a problem in soybean cultivation due to the slow seedling development of soybeans. Another benefit of narrow row spacing is the observed elevated first pod height (Mechtler 2012 and Soldati 1999, 678) as well as an earlier closure of the plant canopy leading further to reduced radiation on the soil surface, improved microclimate, reduced evaporation and improved water supply (Mishra 2010, 214f.).

If soybeans are drilled or planted in narrow row spaces in order to reduce weed pressure, enhancing the seeding rate is advised. According to Mishra (2010, 214), 125 kg/ha in 20 cm rows should be aspired, while Uri (2000) suggests an increase of 10-20% seed rate in narrow rows compared to row distances of 1 meter or more.

On the other hand intended mechanical weed control requires larger row spaces. If for instance hoeing is intended, an adaption in row spacing (e.g. 25 to 35 cm) should be allowed for (Diepenbrock et al. 1999, 249).

Moreover reduced plant density correlates with increased yield, but if a combine harvester is used at harvest, higher plant densities lead to decreased yield loss. This results in a negative correlation between the utilization of a combine harvester and plant density which should be taken into account when planning row distances and seeding rates (Diepenbrock et al. 1999, 246).

In Upper Austria most commonly found row distances in conventional soybean stands measure 12 cm, which is rooted in wheat cultivation and associated machinery (LK OÖ and LK NÖ 2010, 9). Apparently though seed rate and row distances are reported to have a more significant impact on weed infestation rates than does plant geometry in soybean stands. Hence, elevated seed rates (150 kg ha^{-1}) have been found to significantly reduce weed infestation compared to seed rates of 100 and 125 kg ha^{-1}. Similarly narrower row spacing (25 instead of 45 cm in India) lead to 21.7% more effective weed control as well as an increased grain yield of 15.6%. Crop geometry however had no significant impact on weed infestation rates (Mishra 2010, 214f.).

3.1.2.7 Crop rotations Crop rotation is generally accepted as a good method to control weeds and soil borne diseases (Liu et al. 2008). Moreover crop rotation is a rather powerful tool in plant production with significant potential in improving a number of factors. Besides leguminous crops are of major importance within crop rotation systems for example due to positive effects on soil fertility, micronutrients, reduced soil compaction and reduced weed infestation (EIP et al. 2014a, 5).

Since weed control is one of the major challenges in soybean cultivation (see Chapter 3.1.2.8 on competitiveness against weeds), one main focus should be placed upon enhancing the weed suppression ability through crop management. Crop rotation is rather influential in respects to weed suppressive abilities (especially in early crop developmental stages and during ripening) of crop stands. Hence, by choosing suitable preceding/subsequent crops, the rather poorly developed weed suppression ability of soybean may be defused and weed pressure on the site kept low. In addition suitable intercrops should be chosen with respect to enhance e ciency in weed control. Bene cial e ects have been especially associated with preceding crops such as root crops or wheat combined with catch crops (Friedel et al. 2003).

Generally speaking the soybean is claimed to be self-compatible, but this statement comes with restrictions (Brandstetter et al. 1993, 3; Mechtler 2012 and Pistrich et al. 2014, 14, 57). For instance cultivating soybean on the same plot for e.g. two years in a row could be favourable for rhizobacteria (see Chapter 3.1.2.9.1 on the speci city of host-rhizobacterium interaction) (Mechtler 2012). This comes at the cost of an increased threat of soil borne diseases like *Sclerotinia* (see Chapter 3.1.2.11 on diseases) or *Rhizoctonia*. Grain legumes in general should therefore only be cultivated on the same locations in an interval of 4-6 years. Additionally it is strongly advised to avoid crops in cropping rotations with soybeans that are known to be susceptible to *Sclerotinia*, or at least to expand the time in between more *Sclerotinia*-susceptible crops (Mechtler 2012 and Pistrich et al. 2014, 14). Current recommendations in respect to soybean cultivation consequently aim at avoiding soybean on the same plots for two or more years in a row, but also at avoiding enhancing weed pressure (Brandstetter et al. 1993, 3).

Generally though all winter wheat species that are sown late in the season are suitable as crops that subsequent soybean (Friedel et al. 2003 and Pistrich et al. 2014, 57).. Other suitable pot-soybean crop species include corn, fodder beet or potato (Pistrich et al. 2014, 57).

Bene cial pre-soybean crop species should ideally be marked by high demands of mineral N (Friedel et al. 2003 and Pistrich et al. 2014, 57) and include for instance wheat, corn, sugar beet (Brandstetter et al. 1993, 3) or potato (Diepenbrock et al. 1999, 247 and Soldati 1999, 677). Less suitable preceding crops would be sun ower or rapeseed because of the threat of *Sclerotinia sclerotiorum* (Mechtler 2012 and Pistrich et al. 2014, 57), which is why it is strongly recommended to maintain a gap of at least four years between those crops and soybean in order to avoid *Sclerotinia* (Brandstetter et al. 1993, 3 and Pistrich et al. 2014, 57). Other less suitable preceding crops include other legumes like pea or faba bean (*Vicia faba*) (Soldati 1999, 677). Furthermore soybean could be quite easily introduced into the cropping cycle if wheat species have already been established as no additional machinery would be needed (Soldati 1999, 677).

If soybean is planted on a plot for the rst time, inoculation of the seeds with rhizobacteria is considered to be important (see Chapters 3.1.2.9.1 on inoculation and 3.1.2.9.1

on the speci city of host-rhizobacterium interaction) (Diepenbrock et al. 1999, 247). At the same time it is crucial to prevent N which was accumulated through soybeans from leaching (Soldati 1999, 677) erosion or volatilization , especially during winter (Brady and Weil 1999, 482) and during/after hoeing legume stands. These times are rather critical for N leaching (Friedel et al. 2003), which is why special attention should be placed upon preventing N which was aggregated through soybean, from being eluded by introducing suitable subsequent crop. Hence, if a summer crop is chosen as subsequent crop after soybean, it is also advisable to additionally use a winter intercrop (in order to ligate N) (Friedel et al. 2003 and Mechtler 2012).

3.1.2.7.1 Crop rotations in organic farming systems In a legume-based organic crop rotation farming system, legumes should constitute a minimum share of 25-30%. The share should be closer to 30% if no grassland is incorporated in an agro system because grain would require 110 kg N/ha in a system without grassland (Friedel et al. 2003).

Friedel et al. (2003) further suggest that legumes intended for animal feeding should be incorporated into the cropping cycle in a year in which di erent wheat species and other non-leguminous crops are grown, in order to help maintain su cient levels of N within the soil for 2-3 subsequent years. This time of not incorporating legumes into the cropping cycle is due to diseases commonly related to insu cient crop rotations, as already mentioned in the section above. Therefore diseases related to cropping rotations are an important topic in organic agriculture as well. Referring to this, recommendations for organic farming suggest a cultivation gap of up to six years between cultivations of either lucerne or clover (Friedel et al. 2003 and Mechtler 2012). These recommendations of course imply a pause in cultivating legumes, leading further to possible bottlenecks in respect of su cient available organic N in the agricultural soil throughout the cropping cycle (Friedel et al. 2003) therefore introduced the option of using grain legumes as intercrops.

Such grain legumes used as intercrops could also be bene cial for animal feeding, as e.g. soybean would further provide advantages for livestock farming systems (see also Chapter 3.1.4.1 on animal feeding) including animal fodder of high quality, regulation of weeds due to shading on the plots and support in building up humus. In addition, soil structure and soil fertility would be improved (Friedel et al. 2003 and Mechtler 2012) and mobilization of nutrients would be enhanced due to well established deep root systems (Friedel et al. 2003; Mechtler 2012 and Soldati 1999, 677).

Figure 11: Heavily weed infested soybean field
The picture shows a site with high weed pressure from volunteers (sun ower) and *Chenopodium/Atriplex* species in Carinthia, 2014.

3.1.2.8 Competitiveness of soybeans against weeds Weeds may have high competitiveness towards crops by taking up nutrients and water, limiting space as well as acting limiting by competing over access to light through shading.

The soybean has a rather slow juvenile development. In combination with its weak competitive strength towards weeds and partly large row spacings, this results in high susceptibility to weed infestation, which is particularly problematic in early developmental stages (Vollmann et al. 2008, 314; cf. LK OÖ and LK NÖ 2010 and Mechtler 2012) but recurs in late soybean developmental stages especially when foliage is lost and ripening is delayed (Vollmann et al. 2008, 314; cf. LK OÖ and LK NÖ 2010; Mechtler 2012 and Schori et al. 2003, see Figure 11).

Haberlandt (1878, 93) mentioned well established soil surface shading properties of soybeans as soon as the canopy is fully developed, leading to low weed infestation rates at this particular developmental stage. But otherwise, weed control may be a rather big challenge. Weed infestation and weed control in soybean cultivation is therefore a major topic (cf. LK OÖ and LK NÖ 2010; Mechtler 2012 and Vollmann et al. 2008, 314). Thus, the following chapter discusses intrinsic weed processes in agricultural systems in general (at the beginning) and in soybean stands in particular (following thereafter) quite at length.

3.1.2.8.1 General thoughts on weeds in agricultural systems In general there are numerous di ering de nitions on *weeds*. According to Baker (1974), *weeds* are plant species which, in a given geographical area, expand their population primarily (or even exclusively) in habitats which have been disturbed by humans and are not regarded as being useful for crop cultivation (Baker 1974). Baker also provides a list, which gives further indicators of what characterises *weeds* (Baker 1974):

1. Many environments may provide ideal germination requirements
2. Seeds have great longevity and germination ability
3. Fast growth especially until owering which accounts for short life-cycles
4. Seed production period is stretched as long as growing conditions allow for it
5. Mostly self-compatible, even though not entirely autogamous
6. If cross-pollination takes place, either wind or unspecialized pollinators are used
7. Exceptionally high number of seeds
8. Seed production is possible in a variety of environments, which accounts for high plasticity and tolerance towards impact/disturbances
9. Seeds may possess certain adaption mechanisms to be able to spread throughout long distances, but are also equipped for short distance travelling
10. If this weed is a perennial, the vegetative dispersion is very e ective and the weed itself may be able to regenerate from small pieces. In an agricultural setting this ability of the weed species may require a lot of e orts to deal with
11. Weeds may also be able to compete with di erent (crop) species

Agricultural weed oras may di er in their composition, depending on the habitat, as well as on the climate and cropping system, but all of them constitute a completely self-contained group of plant species, because all of them (even if they di er in intensities) successfully invade and intensively infest heavily disturbed agricultural areas, despite considerable e orts to remove them. As a consequence, weeds in an agricultural context are subject to severe attempts of elimination. Murphy and Lemerle (2006) therefore referred to them as *[...] plants out of place* [...] .

Weeds in this sense only appear because of the disturbances in environments shaped through agricultural crop cultivation (Neve et al. 2009), to which they might have been subjected through wind or water, animals, machinery and vehicles, or through contaminated seeds or fodder (Murphy and Lemerle 2006).

It is generally accepted that more diverse cropping systems (achieved e.g. by a higher diversity within crop rotations) would lead to a broader spectrum of weeds, reducing specialised, dominant and persistent weed species compared to less diverse cropping rotations (Murphy and Lemerle 2006).

As a result, weed adaption potential is of vital importance and is related to two prerequisites, genetic variation and *selection pressure* (Neve et al. 2009).

a) Selection pressure

Such production related measures, or disturbances, in agriculture include crop rotation, the use of herbicides and fertilizers, measures to improve soil fertility, tillage as well as mechanisation techniques at harvesting. All of these agronomic practices cause selection pressures on weeds (Murphy and Lemerle 2006 and Neve et al. 2009). An overview of management practices for weed prevention is given in Figure 3.1.2.8.3.

If similar agronomic measures are performed on a regular basis, but will discontinue at one point, this inconsistency can also be seen as weed control tactic, because the environment to which the weed population has adapted changed and may in uence the distribution of weeds as well as weed/crop competition mechanisms, growth and physiological traits of weeds. Challenges for weeds therefore increase if crop rotations or agronomic management measures are more diverse and discontinue in some way, with high numbers of selection pressures on the weeds (Murphy and Lemerle 2006).

Furthermore, selection pressures may originate from environmental changes, including changes in soil conditions (pH level, moisture content, temperature, soil type,...), quantity as well as quality of light, air, precipitation (Murphy and Lemerle 2006), local climate, weed management strategies and cultivation techniques (Neve et al. 2009). More diverse environments hence prevent the evolution of few but highly adapted and troublesome weed species. Vice versa this means that if continuity is practiced on farm-level, selection towards this continuity may result in locally well-adapted weed-ecotypes that might prove di cult to control (Neve et al. 2009).

In addition, as stated by Baker (1974), weeds are characterised by their high plasticity, which is part of their survival strategy and which allows them to adapt to changing environmental conditions (Baker 1974; Murphy and Lemerle 2006 and Neve et al. 2009). Due to short life-cycle and a high number of seeds, weeds are also able to adjust quickly (Baker 1974).

According to Murphy and Lemerle (2006), this plasticity roots in genetic variation that

Table 10: Summary of management practices on weed ora shifts

Table 1. Summary of management practices on weed flora shifts

Management practice	Selection pressure exerted	Selected weedy traits	Weed population shift
Crop rotation			
Continuous cropping	Simple repetitive agronomic practices	Crop mimicry	+ Broadleaf weeds in broadleaf crops + Grass weeds in cereal crops + Summer weeds in summer crops
Rotational cropping	Diversity in crop species, seeding rates, fertilisers	Competitive ability	+ Species with competitive traits (e.g. rapid germination and early growth, rapid canopy closure, greater height, tillering or branching)
	Pasture phase	Avoid grazing and/or forage removal	+ Unpalatable species + Early seed set
Reduced tillage/stubble retention	Low soil disturbance	Ability to germinate from shallow depths	+ Wind dispersed species + Perennial/biennial species
	Earlier sowing	Delayed emergence	+ Annual grasses − Early emerging species
	Allelopathic effect from crop residue	Tolerance to allelochemicals	− Species susceptible to crop exudates
	Mechanical barrier	Enhanced seed dormancy	+ Species with short-lived seeds
	Changes soil environment		
	Soil flora and fauna	Increased seed predation	− Species prone to predation by soil fauna
	Repeated application of non-selective herbicide	Tolerance to non-selective herbicides	+ Species resistant to non-selective herbicides
Herbicide use	Reliance on single herbicide group	Herbicide resistance genes that do not incur fitness penalty	+ Species herbicide tolerance
Soil amendments	Increased nutrient levels	Physiologies that tolerate high nutrient levels	− Species with intolerances to high nutrient levels
	Timing and placement		
	Tolerance to toxicities		
	pH		
Harvesting	Mechanised harvesting	Avoid seed removal at harvest	+ Early maturing species + Small seeded
		Mimicry of seed types (cereals and grass weeds)	

(+) Indicates an increase in abundance.
(−) Indicates a decline in abundance.

Source: Murphy and Lemerle (2006).

occurs naturally and is responsible for fitness-related characteristics including resistance to pathogens or seed dormancy. In contrast, Neve et al. (2009) report that weeds tend to be treated and regarded in analogy to *genetically uniform crops* (Neve et al. 2009), with a focus on physiology and agronomy. However traits like plant ecology and evolution are more or less neglected, despite of being vital for the understanding of weed management and weed biology.

Due to large numbers of influencing factors with respect to weed developments it is difficult to mark precise factors that influence certain processes in weed population dynamics. This would especially be the case if the study region would cover a larger area, causing particular difficulty in attempts to predict shifts in weed compositions in whole regions (Murphy and Lemerle 2006).

Therefore, to be able to get a clear picture of potential weed adaptions, it is necessary to initially collect data in respect of being able to estimate the extent, the significance and the structure of the present genetic diversity, upon which further conclusions may be drawn (Neve et al. 2009).

b) Genetic variation in weed populations

Opinions concerning the degree and the significance of genetic variations in weed populations in agricultural systems are quite diverse. One of the two main views includes that a) an initial colonisation takes place by few plants, which subsequently lead to conservation through the *founder effect* (Neve et al. 2009) and genetic variation is consequently being created by outside pressures, leading to genetic bottlenecks. The other version b) however states, that a variety of non-native species will colonise and consequently create a melting pot of genotypes, maybe resulting in well-adapted variations (Neve et al. 2009).

Since weed management strategies constantly develop, weed response is thought to follow in an equal pace. For example, where glyphosate-resistant crops (as used e.g. in GM crops) are cultivated and used quite intensively, problems with glyphosate resistant weeds were reported to have tremendously increased. This is also a reason why Neve et al. (2009) strongly emphasise an incorporation of findings and principles from the field of evolutionary ecology into applied weed research in agricultural settings (Neve et al. 2009). An overview of dynamic developments interacting between crops, weeds and agriculture is presented in Figure 12.

3.1.2.8.2 Weeds as major problem in soybean cultivation As stated in the beginning of the chapter, weed control is a major topic in soybean production and probably the most pressing challenge in soybean disease management (Österreichische Arbeitsge-

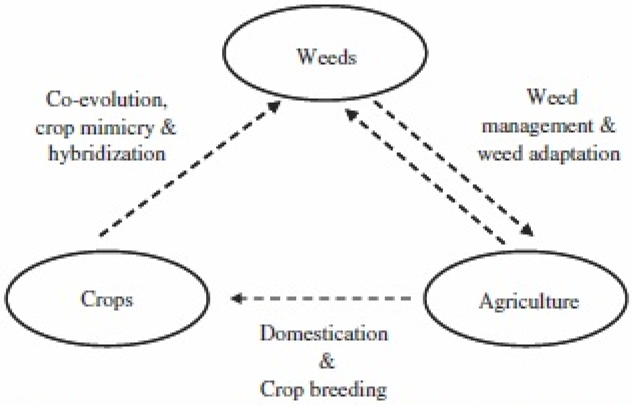

Fig. 1 A schematic representation of the 'Weed Management Arms Race' showing the coevolutionary dynamics of interactions between humans, crops and weed populations. Unconscious and conscious human selection during domestication and subsequent breeding has produced modern, specialized crop species and varieties. Widespread cultivation of these crops has created 'opportunity space' for the invasion of agricultural land by ruderal plant species and subsequent crop–weed coevolution has resulted in the evolution of highly adapted weed ecotypes that mimic the crop lifecycle and morphological characteristics. This evolution of highly adapted weeds has stimulated the development of sophisticated weed control tools and these highly effective tools (for example, herbicides) have exerted extreme selection pressure for weed adaptation. The continuing and ongoing development of crop varieties, weed control tools and weed management systems in response to weed adaptation requires a greater acknowledgement of the key role of evolutionary dynamics in management of agricultural weeds.

Figure 12: Concept of coevolutionary dynamics in weed populations

Source: Neve et al. (2009).

meinschaft für integrierten P anzenschutz 2013, 15). Field trials e.g. in Switzerland showed that herbicide use was the most exible way to handle weed infestations. But due to a diminishing pool of accredited herbicides, this challenge of handling weeds in an appropriate way is made even more urgent (cf. LK OÖ and LK NÖ 2010; Schori et al. 2003 and Vollmann et al. 2008, 314). This is why mechanical weed control mechanisms pose an important supplement even for conventional soybean producers and why trials are conducted to further enhance the mechanical weed control potential and its practicability (cf. LK OÖ and LK NÖ 2010, 201; Schori et al. 2003 and Vollmann et al. 2008, 314). Suitable mechanical weed control practises, as already practiced in organic farming systems on a global scale, include hoeing and harrowing (Schori et al. 2003 and Vollmann et al. 2008, 314) (see also Chapter 3.1.2.2 on soil seedbed preparation). In addition, suitable crop rotations and consequent weed control are highly emphasised in soybean cultivation, because high weed pressure within soybean stands also leads to negative e ects for subsequent crops and poses the threat of yield loss (cf. LK OÖ and LK NÖ 2010 and Vollmann et al. 2008, 314) (see also Chapter 3.1.2.7 on crop rotation and weed control).

Furthermore, weed-crop competition remains a continuing and rather complex obstacle experienced by producers all over the world (Mishra 2010, 210 and Vollmann et al. 2010). Most dominating and critical weed infestations are created by weeds that belong to an annual, seed-propagated type (Vollmann et al. 2010) that emerges early in the season or at planting time (Mishra 2010, 210 and Vollmann et al. 2010).

Especially early infestation of high weed densities proved to be critical, because they may account for reduced crop quality, substantial yield loss, a decrease in harvest e ciency and higher cost for soil preparation or increased appearances in pests and diseases. Reasons for such drastic outcomes due to weed infestation, particularly associated with the weak juvenile developmental stage of soybean, are founded in a lack of solar radiation, insu cient nutrient supply (with mostly inorganic nutrients) and inadequate soil moisture for the crop caused by the presence of the weeds and their competitive strengths (Mishra 2010, 210 and Vollmann et al. 2010).

Vollmann et al. (2010) also observed how pressure from a seed-distributed type of weed, such as winter oilseed rape, had signi cant impact on quality characteristics of seed yield and other phenological and agronomic parameters. Furthermore during early developmental stages, mutual shading may occur between crops and weeds during early developmental stages, as older/bigger leaves may shade younger plants, which consequently stay weaker and smaller (see Chapter 3.1.2.12.6 on foliar disposition). Moreover parameters such as light quality alteration, derived e.g. from re ectance from weeds, may also impact crop development even though these in uences, deriving from altered light quality, are not directly creating a weed-crop competition (Vollmann et al. 2010). Nevertheless this aspect is also relevant for systems practicing intercropping (see also Chapters 3.1.2.12.6 on foliar disposition; 3.1.2.4.1 on intercropping).

Furthermore, beneath the soil surface, more established roots and root systems of weeds may be able to access water and nutrients better and outrun younger, shorter roots from soybeans. Therefore it is vital to remove competing weeds during these early stages (Mishra 2010, 211f.).

Potential yield loss caused by weeds consequently depends on various factors, including weed species and developmental stage and soybean cultivar, as well as environmental conditions, infestation rates and whether or not weeds are capable of releasing allelochemicals. For example, in Indian environments most loss which could be linked directly to weed competition have been detected to occur 45 days after sowing. During these early stages, grasses pose the most dominant threat, followed by sedges and broadleaf weeds later in the cropping season, emphasising the high susceptibility of young soybean plants, but also illustrating how the appearance of certain weed species is adapted to the crop stands. Interestingly though, total yield loss in the example given reportedly occurred at less than maximum weed density (Mishra 2010, 210 .).

Most common weed species found in Austrian soybean stands vary slightly throughout the regions and according to site speci c and regional climate conditions. Most prominent weed species include *Chenopodium* and *Atriplex* species, Camomile, Amaranth varieties, *Solanum nigrum*, varieties of millet, *Galium aparine* varieties, thistles, eld bindweed (*Convolvulus arvensis*), *Rumex*-varieties and *common ragweed.* (Österreichische Arbeitsgemeinschaft für integrierten P anzenschutz , 15 and Pistrich et al. 2014, 58). In the following, some weed species and varieties are shortly portrayed in further detail in order to give an impression of the properties and characteristics of these weeds:

- *Chenopodium- and Atriplex* are only distinguishable due to fruit-related features that appear very late in the season and require a lot of experience to di erentiate properly (Holzner and Glauninger 2005, 42). Most members belonging to this family are annual and highly competitive, have long-living seeds, are quickly emerging and are furthermore known as pioneer plants, which use open spaces in nutrition rich soil. They can also take up and accumulate high concentrations of nitrate nitrogen, which should also be taken into account if the infested material is used for animal feeding purposes (Holzner and Glauninger 2005, 42, 48f.).

- Camomile belongs to the *Asteraceae* family. *Matricaria recutita/Matricaria chamomilla* or *Anthemis cotula* which are most commonly found in cropland in Austria. However, even though both *Matricaria recutita/Matricaria chamomilla* and *Anthemis cotula* are camomiles, their requirements as well as their competitive strengths and suitable mechanisms to control them are diverse. Generally though, camomile does not belong to problematic weed species that are di cult to control in cropland (Holzner and Glauninger 2005, 110 .).

- Amaranth species originated in tropical and subtropical regions in the Americas and tend (similarly to the *Chenopodium/Atriplex*-species) to accumulate high nitrate concentrations that could be dangerous when impurifying animal fodder, because stored nitrate could be reduced to highly toxic nitrite (Holzner and Glauninger 2005, 17). Within crop stands the most commonly found Amaranthus species is *Amaranthus retroflexus,* which is highly competitive and produces a vast amount of seeds. If herbicides are applied in an early developmental stage of the weed, e ciency and subsequently weed control success is often low (Holzner and Glauninger 2005, 17).

- Black nightshade (*Solanum nigrum*) is a summer-annual species in the *Solanum* genus. Emergence is late in the season and its competitiveness is rather weak. In some regions of Carynthia, Styria and Upper-Austria, black nightshade is relatively common. Due to the well disposable, broad variety of herbicides, *Solanum nigrum* is not too di cult to control, even though *triazine*-resistant plants have been observed (Holzner and Glauninger 2005, 184). However black nightshade is particularly problematic in plant stands which are harvested with a combine harvester (cf. LK OÖ and LK NÖ 2010),

- Millet originated in warm subtropical regions. In Austria, it is an annual plant which is di cult to manage. To emerge, they need relatively high soil temperatures between 10 and 20°C. But due to too high input rates of *atrazine*-containing herbicides, they have become rather insensitive towards this compound. Additionally, diverse responses towards *sulfonylurea* have been reported (Holzner and Glauninger 2005, 68 .).

- Ragweed (*Ambrosia artemisiifolia)* is a summer-annual and highly competitive weed which has a blooming-period late in the season (between August and October) and is recognisable due to its tall and upright habitus of 50-200 cm (Holzner and

Glauninger 2005, 125). Its vast amount of produced pollen is highly allergic and 3 to 5 times more aggressive than other grass-pollen (AGES et al. 2010). Even small amounts (ve to ten ragweed pollen per cubic metre) cause allergic reactions, leading to asthma, heyfever-like reactions or trachoma. Furthermore, pollen can travel 100ds of kilometers by wind (AGES et al. 2010) and seeds in soil have high longevity with high risk of being spread (Holzner and Glauninger 2005, 125) thanks to their extraordinarily high capability to adhere to almost all materials. They are predominantly spread by building activities, mowing- or harvesting machines, seed mixtures for intercropping, bird feed, or not certi ed infested crop seeds, e.g. produced on farm (AGES et al. 2010).

Until 2005, ragweed was only found in warmer regions of Austria, especially in sandy soil types which heated up quickly. High infestation rates have furthermore been reported in corn- and pumpkin acreage. Still, in Hungary and Slovenia high infestation rates have been announced for years. Today, ragweed is commonly found in sun ower elds, on waysides where debris and rubble is stored or near building sites (AGES et al. 2010, Holzner and Glauninger 2005, 125).

- *Galinsoga ssp.*: Gallant soldiers have quick youth developmental stages during which they accumulate a lot of nutrients. This is why they have a high competitive strength at that particular (accumulating-) stage which drops in further development. Especially in years of high precipitation *Gallant soldiers* show enhanced growth, whereas in dry years they are frequently missing completely, due to a lack in required moisture for emergence. Mechanical weed control mechanisms repeatedly lead to spreading, because plant residue that is left on the eld may be able to redevelop roots quickly. Herbicides are available especially for infestations late in the season (Holzner and Glauninger 2005, 117).

This selection of weeds frequently encountered in Austrian soybean stands also outlines the wide variety in weed physiologies which results in the necessity of searching for soybean varieties that are able to strongly suppress weed pressure over the full duration of a cropping season. However it seems to be very di cult to breed soybean varieties that would have suppressive abilities against early appearing weeds as well as against weeds appearing later in the season and/or towards weeds, which cause trouble throughout the cropping cycle (Jannik et al. 2001).

3.1.2.8.3 Loss accounted for by weeds In attempts to quantify environmental and economic costs caused by weeds, reports published point out yield loss accounted by weeds on a global scale to be as high as 34% , which is more than any other crop pest (Neve et al. 2009). Mishra (2010, 210) stated average loss in soybean cultivation due to weed pressure to be as high as 20 to 85%, depending on various factors such as environmental conditions, soybean cultivar, row spacing, duration of the weed pressure, growth type and density of weed occurrance. Interestingly though, the percentage of yield loss caused by weeds has not changed much during the last 50 years.

Therefore Neve et al. (2009) introduced the idea of a *[...] weed management [at] arms race [...]* and drew parallels to the *evolutionary arms race* (Neve et al. 2009) by stating that attempts of breeders, farmers and companies in the pest-prevention/disease-prevention sector have reached a certain border that is very di cult to cross. Simultaneously though, pathogens and their hosts would have reached some sort of balance as well (Neve et al. 2009). Jannik et al. (2001) whereas suggest to consider an incorporation of a trade-o theory in order to understand competition potentials between soybean and weed species.

In respect of resource competition, weeds compete with crops over light, water and nutrients. In India for example, weeds have been reported to take up an average of 30 60 kg nitrogen ha^{-1}, 8 10 kg phosphorus ha^{-1} and 40 100 kg potassium ha^{-1} from the soil. In soybean elds, take-up rates measured 53.24 kg nitrogen ha^{-1} and 9.30 kg phosphorus ha^{-1} (Mishra 2010, 210).

An idea on how to quantify weed suppressive potential in soybean breeding was introduced by Jannik et al. (2000, as cited in Vollmann et al. 2010), who propounded the concept of a selection index for breeding purposes. Although according to Vollmann et al. (2010), to be able to select soybean varieties with superior suppressive abilities on cultivar level would be needed to select soybean varieties with superior suppressive abilities. However, this additional genetic information would still be scarce.

Generally though, quick germination and vegetative growth as well as early plant height are reported to be positively correlated with weed suppressive potential (Murphy and Lemerle 2006 and Vollmann et al. 2010), as are early root growth and increased root size, quick canopy production and -closure. Other bene cial traits include quickly expanding leaf area, great plant height, bene cial seedling vigour and seed size (more vigorous plants produce larger seed sizes) as well as enhanced ability to branch or tiller (Mishra 2010, 215 and Murphy and Lemerle 2006).

In an experiment with a three-year running period, Vollmann et al. (2010) used winter oilseed rape to simulate weed pressure in 10 early maturing soybean cultivars in Austria. Results showed less yield loss in early maturing lines compared with later maturing ones, which was connected to elevated weed tolerance of the latter rather than to suppressive e ects. Signi cant e ects on agronomic traits and seed quality though included weed treatment, genotype and year.

Higher weed infestation, especially combined with osmotic stress in more sensitive developmental stages of soybean, led to reduced plant height. This was stated to be most likely linked to competition over water and nutrients, although other traits such as delayed maturity, reduced seed yield as well as reduced thousand-seed weight amongst others have been implicated as well. It was therefore suggested to use plant height as indicator (Vollmann et al. 2010).

Curiously enough though, enhanced weed infestation in one variant was also reported to have led to increased yields, which is believed to be a result of high rates of precipitation, well aerated soil conditions, bene cial soil structure, root systems, soil microorganisms and water uptake due to light ground cover (Vollmann et al. 2010).

Generally, ground cover is associated with shade-avoidance reactions of the plants including enhanced plant height or decreased branching. These speci c reactions are based in a recognition mechanism of the crops to changed far-red light ratio, which is horizontally re ected from ground cover plants (Vollmann et al. 2010).

Weed prevention management strategies in soybean cultivation

In respect of *Good Agricultural Practice* (GAP) methods, weed control should begin with e orts in preventing intrusions of new weed species for as long as possible. Such attempts include (as best case scenario) an exclusive utilisation of certi ed seeds, an application of completely decomposed organic manures, avoidance of letting the weeds enter a reproductive phase and a cleaning of the machinery before it is used, particularly if the machinery is shared between farmers or plots (Mishra 2010, 212f.),

Generally speaking cultivation managing practices are, compared to herbicide use, the most cost-e cient and eco-friendly options for weed prevention and suppression operations (Mishra 2010, 213f.). Furthermore, in agricultural systems that have to rely on non-chemical methods (e.g. in organic farming systems), cultural weed prevention methods are of utmost importance (Vollmann et al. 2010).

i) Crop rotation

One of the major tools in weed management to reduce the seedbank of weeds in the soil is crop rotation (Mishra 2010, 214, see Chapter 3.1.2.7 on crop rotation and weed control). The intention of introducing crop rotations includes the attempt to create a more challenging situation by preventing or at least delaying weeds in their ability to adapt too quickly (Mishra 2010, 214 and Murphy and Lemerle 2006). For instance, in places where solely maize monocultures or alternating soybean-maize rotations are practiced, persistent and difficult to control summer annual weeds are frequently spreading (Murphy and Lemerle 2006).

If however weeds have enough time (e.g. as a result of lacking alternation and periodic cultivation of few crop species) to copy certain characteristics (mimicry) of the surrounding crop stand, weeds adapt easier and consequently become more difficult to control. Chemical solutions, for example, may become more difficult to introduce due to similar life cycles of crops and weeds (Murphy and Lemerle 2006).

For this reason, there are a number of weed species which are typically related to particular crops. An increase in such weed species often occurs when cultivation is intensified. Besides, if a location is particularly suitable for crop production, it is most likely a good habitat for weeds as well.

In conclusion, weed pressure may be slowed down or even reduced if crop rotations include crops with highly diverting characteristics like considerable alteration in the life-cycles or planting dates of subsequent crops in order to make it more difficult for weeds to adapt (Mishra 2010, 214). In addition, the competitive ability of crops toward weeds can also be increased by adjusting agronomic production parameters such as the choice of adequate crop species, genotypes, a higher seed rate or optimum spatial distribution of plants, as well as fertilizer use (Murphy and Lemerle 2006).

Another strategy includes an incorporation of fallows in crop rotations in order to diversify weed populations, which is performed in rather dry regions like Australia, Poland or Canadian prairies. Research results suggest fewer weed species found in fields that incorporated fallows. Moreover there were less exuberant appearances of species such as *Amaranthus retroflexus*, *Chenopodium album* and *Setaria vidris* (Murphy and Lemerle 2006). Nevertheless (Brady and Weil 1999, 481f.) state that ground cover would always be more preferable than fallows (see Chapter 3.1.2.4 on tillage systems and Chapter 3.1.4.2.2 on food security).

ii) Mulching

In order to moderate soil temperature as well as conserve soil moisture and light availability, mulching and leaving crop stubbles on the field could be useful and effective measures. Mulch (materials that are left or applied on the field to cover the soil surface) could be anything from crop residues, paper, plastic films or gravel. Such ground cover prevents weed germination and physically suppresses weed emergence. (Mishra 2010, 214 and Murphy and Lemerle 2006)

If crop residues form a mulch layer, exudates and allelochemicals (chemical suppressants) additionally help to increase biological activity and o er suitable surroundings for predators (Murphy and Lemerle 2006). However, it is not considered to be a longterm solution against perennial weeds species. Furthermore, mulching alters chemical processes and constitutions such as allelopathy, toxic microbial products as well as the pH value and may prove not to be economical (Mishra 2010, 214). Moreover crop residues shift the C:N ratio.

Stubble crop residues have proved to be able to alter dynamics of ora and fauna. They subsequently in uence the spatial variation of weed seeds, the size of the seedbank and the dormancy, as environmentally induced decay is in uenced (Murphy and Lemerle 2006).

In India soil solarisation is sometimes practiced before cultivation. There a transparent polyethylen lm covers the soil and solar radiation leads to a hypothermal reaction that heats up the soil underneath the plastic lm for a period between 32 days/up to 5 weeks (Mishra 2010, 213f.). This practice leads to a reduction in soil borne diseases and reduces the germination rates of weeds, but also reduces soil microorganisms. Besides, it is a rather cheap way of pest and disease control.

iii) Mechanical methods

Mechanical weed management methods are most successful during the seedling stage of weeds and when these mechanical measures are performed during dry soil conditions to ensure well aered soil and prevent compaction. Soil aeration may also be improved if mechanical measures include a break-up of the soil surface crust (see Chapter 3.1.2.4 on tillage systems). Blind-harrowing could be performed after seed deposition (pre-emergence of the seedlings), when the seedlings are still covered by roughly 2 cm of soil. After soybeans reach the 4-6 leaf-stage, hoe-harrowing could be performed during post-emergence stag (Brandstetter et al. 1993, 5).

iv) Chemical methods

Weed populations emerge at di erent times during the crop cycle. Hence, weeds are controlled mostly by pre-emergence (Mishra 2010, 216) and post-emergence herbicides (see Table 11). Herbicides should not harm or injure crops or even subsequent crops and should therefore only be applied under suitable conditions (e.g. su cient moisture content in the soil). Instructions should be checked carefully as chemicals need to stay long enough in an active form in the soil to unfold their e ect, but short enough not to cause negative e ects on crops and the environment e.g. through leaching (Mishra 2010, 216, 220).

For instance a study conducted by Kewat et al. (2001, as cited in Mishra 2010, 220) showed that the half-life of *pendimethalin*, the active substance of e.g. *Stomp Aqua,* applied in sandy loam soil types with 1.0 and 1.5 kg ha^{-1} was 24 and 26 days. Therefore, avoiding negative (pollutive) e ects of chemical herbicides and pesticides on the environment is a major issue (Liu et al. 2008).

Due to the development of herbicide tolerant crops (GM-crops), a whole new (research/-market-) area opened up (Murphy and Lemerle 2006). However, on account of shorter cropping cycles and an increasing shift to earlier planting dates, European farmers have been pushed into deeper dependence on a small number of herbicides (Murphy and Lemerle 2006). In farming systems in which *glyphosate-tolerant* soybeans are used, lower application rates could still manage *Setaria faberi,* although higher dosages would be needed in order to control e.g. *Abutilon theophrasti* or *Amaranthus rudis* in the US Midwest. In contrast, completely tolerant weed species such as *Digitaria sanguinalis* and *Ipomoea hederacea* are able to spread even further after *glyphosphat* treatments and - like *Amaranthus palmeri* - cause increasing trouble as they are becoming the dominant weed population (Murphy and Lemerle 2006), requiring additional herbicides to control them.

One must not forget that a use of such a technology requires farmers to continuously use it and to therefore enter into dependence. Besides this system would favour an increase of tolerant weed species which are well-adapted to many characteristics of the farming system like the timing of the herbicide applications, or which possess mechanisms to delay emergence. Equally critical would be a transfer of resistance genes from crops to weeds or an increase of the concentrations of toxic substances of content into biotypes. Even more pressing would be an exchange of resistance genes to an extent which would result in an exit of agricultural ecosystems (Murphy and Lemerle 2006).

Besides studies illustrated that enhanced resistance towards *triazine* in weed biotypeswere only achieved at the cost with in another trait like cut-backs in growth and competitiveness, due to lowered photo-e ciency (Murphy and Lemerle 2006). Hence, trade-o s are detected in weed populations as well and might be useful in weed control.

With prerequisite and detailed knowledge on the weed population, possible ecological impact and the speci c situation given on site, the most economic and e ective method for weed management in soybean would be herbicide applications (Mishra 2010, 216). Recommendations in regard of the vast variety of weed species would consequently be a combination of multiple weed management strategies. In India for example, manual weed-ing is common practice. A promising approach in this setting is to combine mechanical, chemical and cultural methods in order to create a so-called integrated weed management with herbicides used only in the lowest dosage possible (Mishra 2010, 219).

In Austria, as shown in Table 11, pre-emergence herbicide *Artist* appears to be highly effective against pre- and post-emergent weeds, with the exception of post-emerging grasses. *Artist* is a product used especially against *Solanum nigrum* as pre-emergence herbicide. However certain cultivars have been reported not to be compatible with this speci c product (currently the cultivars *Daccor* and *ES Mentor).* E ects after heavy precipitation subsequent to the application could also include slight burning of the leaves of other cultivars (beside the two less compatible mentioned before). Risk of root-neck constriction could appear after using *e.g. Stomp Aqua* or *Spectrum Plus* at demp conditions or due to water logging conditions, leading further to a collapse of the crops (LFI et al. 2014, 64).

During the past few years, the application of the herbicide *Basagran* was heavily debated in Austria and partly (regionally) prohibited due to repeatedly found residues in ground water. *Basagran* was therefore declared to be a hazardous substance for groundwater in regions with light sandy soil types or in regions that previously reported elevated levels of contaminated groundwater (LFI et al. 2014, 58).

The product *Pulsar 40* has received a permit to be used in 2014 if *imminent danger* e.g. of *Solanum nigrum* is given. In such a scenario, farmers are allowed to use this product between the 1^{st} of April to the 30^{th} of June once in three years on the same plot. What is also worth mentioning is the fact that in Austria, the application of herbicides in soybean cultivation is mostly in the sole responsibility of the farmer (LFI et al. 2014).

It should also be pointed out that in soybean cultivation, due to the prohibition of *Basagran* in certain regions, *Pulsar 40* has proven to be most valuable (or even most essential) in curtailing certain problematic weed species (LFI et al. 2014, 58).

3.1.2.8.4 Herbicide use and -resistance Within the last 60 years unidirectional use of herbicides was a major driving force of weed selection. Even more so as herbicides increased signi cantly as widely established single weed control tool. The downside of relying on such a unilateral method is that weed population shifts continuously towards more herbicide tolerant species, which nowadays pose an immense challenge for farmers (Murphy and Lemerle 2006).

Resistance towards herbicides is also pointed out by Powles and Shaner (2001, as cited in Neve et al. 2009) as clear demonstration of the evolutionary potential of weeds, albeit certain weed species or certain herbicides are more likely to develop resistances

Table 11: Accredited herbicides in Austria for soybean 2014

Product	Active component	application rate /ha	price (Euro/ ha)	quitch	amaranth	chamomile	*Chenopodium*/ *Atriplex*	Ragweed
pre-emergence								
Artist	Metribuzin + Flufenazet	2 kg	71	0	+++	++(+)	+++	++
StompAqua	Pendime-thalin	1,5l	24	0	+++	++	+++	+
Spectrum Plus	Pendime-thalin + Dimetha-namid	2,5l	k.A.	0	+++	++	+++	++
Dual Gold	s-Metolachlor	1,25l	33	0	+	(+)	0	0
Sencor WG	Metribuzin	0,3-0,4kg	15-21	0	++	++	+++	+
Successor 600	Pethoxamid	2l	62	0	++(+)	++(+)	++	+
post-emergence								
Basagran	Bentazone	1-2l	41-83	0	+++	+++	+(+)	+(+)
Harmony SX and Zellex CS	Thifens-ulfuron-Methyl + NM	7,5g+ NM Split: 2x7,5g	14	0	+++	+++	+++	+
Pulsar 40	Imazamox	0,5-1l Split: 2x 0,5l	28-56	0	++(+)	+(+)	++(+)	++
post-emergence against grasses								
Focus ultra	Cycloxy-dim	1,5-2l	36-48	++(+)	0	0	0	0
Fusilade Max	Fluazifop-P-butyl	1-2l	28-55	+++	0	0	0	0
Select 240 SC	Clethodim	0,75l	33	+++	0	0	0	0
Targa Super	Quizalofop-P-ethyl	0,5-0,75l	28-41	+++	0	0	0	0
After harvesting								
Clinic, Glyphos, Roundup Ultra u.a.	Glyphos-phat	bis 5l	k.A.	+++	+++	+++	+++	+++

Source: Table adapted Source: LFI et al. 2014, 64.

than others (Neve et al. 2009). Since some herbicides use the same mechanisms, if these are applied in high frequencies on the same field over a period of time, selection pressure is enhanced with some weed species, forming resistance alleles and resistant individual plants (Murphy and Lemerle 2006) after being exposed for a relatively short time of only 3 or 4 generations (Neve et al. 2009).

Most of the research conducted deals with scenarios that have already become reality. If resistances are suspected, the populations are reported, samples are collected and a dose-response curve is conducted. If a resistance is verified, further genetic and molecular data are collected in order to detect the resistance mechanisms (Neve et al. 2009).

It was only recently that this research area revived in integrated weed management and that knowledge concerning weed biology and ecology gained in importance. But, like Murphy and Lemerle (2006) and Neve et al. (2009) stress, evolution and local adaption of weeds remain to be given too little attention. If herbicides are used continuously and extensively, two scenarios become more likely to happen: a) one response would entail either a change in the weed population, or the alternative b) would be the formation of resistances in existing weed populations/of individual plants. The latter scenario would further cause the formation of a resistant biotype. However, both scenarios are more likely to happen if the herbicides used rely on similar mechanisms, stay active in the soil for a long period of time or are being applied frequently (Murphy and Lemerle 2006).

For an efficient herbicide use of accredited herbicides, a mixture of active components that go well together is advised (Österreichische Arbeitsgemeinschaft für integrierten Pflanzenschutz 2013, 10). Corresponding experiments are being conducted on a regular basis and recommendations are being published e.g. by the Chambers of Agriculture in Austria, that provide lists such as Table 11 to keep the farmers updated about the latest developments.

In respect of accredited herbicides in Austria ÖAI Tagungsband (Österreichische Arbeitsgemeinschaft für integrierten Pflanzenschutz 2013, 10) stated that the number of accredited herbicides is rather slim, leading to some problems such as resistant *Chenopodium*- and *Atriplex* species in Upper Austria (Österreichische Arbeitsgemeinschaft für integrierten Pflanzenschutz 2013, 10).

3.1.2.9 Fertilizer use with particular focus on nitrogen (N) fertilizers The quantity of fertilizers used, including the specific composition, should always match soil site conditions, yield expectations and should also factor in site specific cropping cycles. Brandstetter et al. (1993, 5) and (Lembacher et al. 2009). In the case of unbeneficial site properties, an initial fertilizer application of 30 kg/ha^{-1} pure nitrogen is possible, although in most cases not considered to be essential because biological nitrogen xation (BNF, see Chapter 3.1.2.9.1) is assumed to cover the anticipated demands. Requirements of soybean in phosphorus (P) and potassium (K) are rather small. For instance, phosphorus contents of 22,5 to 45 kg/ha^{-1} should only be slightly balanced, preferably leaving a tendency towards undersupply (BMLFUW 2006). Fertilizer should hence not exceed 56-60 kg P_2O_5 and 90[14] kg K_2O per hectare at medium soil quality (class C, according to soil analysis) (Brandstetter et al. 1993, 5 and Schori et al. 2003), whereas Liu et al. (2008) suggest 22.5 kg N/ha and 45 kg/ha P to achieve a middle production level and 30 kg N/ha in combination with 60 kg P/ha for achieving high production levels in China. For high yielding cultivars Liu et al. (2008) also speci ed that soybeans with protein contents of more than 40% would need double the amount of nitrogen compared to wheat or oat per unit biomass production. It is also assumed that total requirements for nitrogen would not be met through BNF as in early stages these types of cultivars would not need a lot of N. Since this would rapidly change during V4 to R1 stage and peaks at R3-R5 stage, additional N sources would be needed during these peaks. The authors also suggest additional phosphorus for high yielding genotypes which should steadily increase until R4 stage, as adequate P supply in topsoil layers would also bene t yield and should not be insu ciently available after R3. Otherwise the authors recommend soluble P fertilization combined with N in R1 stage (Liu et al. 2008).

However nitrogen (N) has major impact on agricultural- and other biological systems (Fustec et al. 2010, 135). In addition N is the second most required element for plants (in terms of quantity), which is only beaten by carbon (C) (Hawkesford 2012, 135), and about 1-5% of the total dry matter of plants consist of N (Hawkesford 2012, 135). Besides good nitrogen supply improves the uptake of other nutrients and further leads to a stimulation of root growth and development (Brady and Weil 1999, 492). It is therefore rather unsurprising that N use is of great signi cance in soybean cultivation (Fustec et al. 2010, 135).

Consequences of N shortages would ultimately lead to limiting e ects e.g. in plant growth (Fustec et al. 2010, 135). Such limiting e ects may be explained using two scenarios a) plants need an exceedingly large amount of N that simply cannot be covered with resources present at the site or b) restricted N supplies need to be distributed amongst a huge variety of processes in which N is a vital compound (Hawkesford 2012, 135). N is needed for instance in the formation of proteins, amino acids, enzymes, nucleic acids,

[14]Schori et al. (2003) even suggest 150 kg/ha K_2O .

chlorophyll, co-enzymes, phytohormones, secondary metabolites and is also important for the use of carbohydrates (Brady and Weil 1999, 492 and Hawkesford 2012, 135) just to mention a few. Thus this circumstance of insu cient N supply may lead to limiting e ects in some associated processes, but it does not mean that these limiting e ects would be detectible or necessarily occurring in all related processes in which N is involved as major compound (Hawkesford 2012, 135). This may o er some insights as to why into reasons for plant producing sectors being prepared to invest large amounts of fossil fuel energy and incur major expenses in order to secure su cient nitrogen supply (Brady and Weil 1999, 491).

Historically the global consumption of nitrogen-containing fertilizers made a major leap during the second half of the twentieth century (Brady and Weil 1999, 521 and Fustec et al. 2010) due to the development of the Haber-Bosch-N (HBN) fertilizers[15] (Schipanski et al. 2010). The introduction was also intended to increase the agricultural yield and food supply (Cooper and Scherer 2012, 398; Fustec et al. 2010 and Liu et al. 2011) and to avoid yield loss (Fustec et al. 2010). However the introduction of HBN fertilizers lead not only to an increase in the quantity of N additions, but simultaneously to a reduction of carbon (C) additions in C-N complexes, and this further resulted in a dissociation of the C and N cycles (Schipanski et al. 2010). To illustrate this with a few gures, in 2012 a little less than 120 million tons of N fertilizers were used globally (FAOSTAT 2014, accessed on July 7th, 2015), although on average crops only use 40-50% of the applied amounts of fertilizers (Cooper and Scherer 2012, 398 and Hawkesford 2012, 135).

But of course the uptake curve of N fertilizers also depend on their compositions. For instance most of the commercially produced nitrogen containing fertilizers provide N in a soluble form such as ammonium, nitrate, or urea, with the latter quickly transforming into ammonium as it hydrolyzes. Essentially the way ammonium and nitrate from arti cial souces are taken up is equvalent to the way nitrogen derived from organic matter mineralization or manures is taken up. Non-arti cial sources deliver ammonium and nitrogen steadily over a much longer period of time and hardly ever in such large amounts all at once as done by arti cial sources (Brady and Weil 1999, 521).

However such scarce applications of arti cial N fertilizers, which release vast amounts of available mineral N during a short period of time, may overburden the assimilatory prcesses of the N-cycle, leading to leaching runo , and in turn posing serious threats

[15]The Haber-Bosh-N fertilizers have started to be commercially produced in 1913 and require high pressure and high temperatures in order to be manufactured. The production process is hence intensive in energy and fossil fuel use (Cooper and Scherer 2012, 398).

for groundwater (Brady and Weil 1999, 521 and Liu et al. 2011), denitrification or ammonia volatilization. The latter especially occurs in alkaline soil types, which are not rich in colloids (clay and humus, which would support absorbing ammonia gas). High temperatures also pose an elevated threat in releasing ammonia greenhouse gases (volatilization) from ammonium-releasing fertilizers such as urea and anhydrous ammonia, animal manure, or decomposing plant residues (especially legume foliage, which is rich in nitrogen) (Brady and Weil 1999, 508; 521; 482).

Intensive use of nitrogenous fertilizers hence cause negative effects by leading to an imbalance of the nitrogen cycle and furthermore to eutrophication (Brady and Weil 1999, 503;482 and Fustec et al. 2010) as well as to a decline in oxygen in aquatic systems, and may even pose serious risks for the health of humans and animals, e.g. if high nitrate levels enter drinking water supplies (Brady and Weil 1999, 503). In addition if nitrogenous fertilizer use would be continued like practised today its production would also speed up the exhaustion of non-renewable energy resources (Fustec et al. 2010). With atmospheric CO_2 levels rising, nitrogen would become a limiting factor in agriculture as well as in many other biological systems (Fustec et al. 2010 and McNeil 2010, 227).

Recommendations for the application of organic matter, N, P and K fertilizers include incorporation into the top centimeters of the soil to reduce ammonia loss (25-75%) (Brady and Weil 1999, 508; 521 and Liu et al. 2008) and (even though probably less feasible) application of smaller amounts in higher frequencies (Brady and Weil 1999, 508; 521). Referring to high yield-cultivars, Liu et al. (2008) also suggest the application of additional nitrogen at the R3 stage.

All these implications however illustrate quite clearly why it is essential to find and establish alternative nitrogen sources (Liu et al. 2011), such as e.g. organic matter mineralization, or the formation of a symbiosis and biological nitrogen fixation (see Chapter 3.1.2.9.1 on BNF; Brady and Weil 1999, 494f.; 514f.). Such alternatives are needed in order help create agricultural systems which are more environmentally friendly (Liu et al. 2011) and which curtail environmental pollution (Fustec et al. 2010). Furthermore soluble HBN fertilizers are often applied at times when active plant growth is lacking resulting in even higher loss (e.g. through leaching) and more severe negative impact on the environment. Therefore a coupled C-N cycle should be re-established to minimize loss while sustaining high yields (Schipanski et al. 2010).

As stated before nitrogen fertilizers contain N in a fixed form such as ammonium, nitrate or urea which allows plants to take up N (Fustec et al. 2010 and McNeil 2010, 227). The two primary inorganic N sources from the roots of higher plants are also nitrate and ammonium, with nitrate dominating in its soil concentration with 1-5 mM compared toammonium with 20 200 µM. This is only in regards to the soil solution in agricultural soil. Additionally negatively charged nitrate anions (NO_3^-) are more mobile than positively charged ammonium cations (NH_4^+) within the soil and hence more readily available/able to move more freely to the root within the flow of soil water. Subsequently nitrate ions are taken up more easily at the root surface in exchange with HCO_3^- or OH^-ions leading to an increase of pH and consequently causing a more alkaline soil solution at the rhizosphere. Positively charged ammonium cations (NH_4^+) lower the pH in the soil solution at the rhizosphere when taken up, due to their exchange with hydrogen ions at the root surface, causing a more acidic pH and also influencing the uptake of phosphates. This latter stated implication in turn is important for nodulation and the formation of a symbiosis with rhizobacteria (see Chapter 3.1.2.9.1 on BNF; Brady and Weil 1999, 492 ff. and Hawkesford 2012, 135). In respect of fertilizer compositions most plants show best growing results after having received a balanced treatment of both ammonium and nitrate (Brady and Weil 1999, 492 ff.).

Moreover nutritional status of crops should be monitored because deficiencies and oversupply e.g. in soybean stands, may be observed and may present phenotypic symptoms. For instance symptoms of N deficiencies include chlorosis, initiated at older leaves, and faster maturity. Other measurable symptoms of N deficiencies include low protein and high sugar contents which is due to a lack in protein synthesis caused by the lack of N. This leads to the oversupply of sugars and carbon chains. An oversupply of N on the other hand would lead to lodging and massive vegetative growth as well as to a delay in plant maturity, reduced flowering and enhanced susceptibility to fungal diseases and insect pests. Additionally, N oversupply may also lead to decreased seed quality e.g. through reduced vitamin content, less beneficial flavour and possibly even accumulation of nitrate (Brady and Weil 1999, 492).

As in reference to Chapter 3.1.2.8 (on competitiveness against weeds) it should also be mentioned that weed species are rather tolerant in their requirements and rather adaptive to fertilizer use commonly practiced in the crops they accompany. But weed populations may still alter over time depending on fertilizer type and amount applied (Murphy and Lemerle 2006).

3.1.2.9.1 Ability of biological (atmospheric) nitrogen (N_2) fixation (BNF) Soybeans not only have the two options of covering their nitrogen requirements through I) mineralization of organic matter or II) artificial N-fertilizer, but they are also able to use a third method which is III) atmospheric N_2 if they successfully form a symbiosis with a certain kind of N_2 - xing bacteria of the *Rhizobium* species (*Bradyrhizobium japonicum*). This third possibility poses an immense potential for soybeans, as it may cover its N demands independent of soil N levels. This process of how rhizobacteria xates atmospheric nitrogen is called *biological nitrogen fixation* (BNF) and consitutes a renewable N source (Brady and Weil 1999, 514 ..; Cooper and Scherer 2012, 392, 398, 405 : Hawkesford 2012, 135; Liu et al. 2011 and Schipanski et al. 2010).

To be more precise atmospheric N_2 is reduced by the bacteria to NH_3 (ammonia). This reduction requires a lot of energy (at least 16 molecules of ATP per N2 molecule in soybean (McNeil 2010, 228, see also Brady and Weil 1999, 949 and Mechtler 2012), the minimum energy requirement being 960 kJ mol^{-1}N xated (Cooper and Scherer 2012, 390), because the triple bond between the nitrogen atoms needs to be broken down (Brady and Weil 1999, 949). In addition energy related to BNF is essential for nodule growth, synthesis of amino compounds and maintaining a stable and suitable environment for the rhizobacteria (for example for maintaining an anearobic setting for the nitrogenase enzyme) (Cooper and Scherer 2012, 392 and Liu et al. 2011). This energy is provided partly by the total amount of photosynthates that gets allocated to the roots (Liu et al. 2011; Mechtler 2012, see also Marschner 2012).

In regards to CO_2 use it has proved to be rather di cult to detect which share of CO_2 is required for nodule growth/maintenance and how much of this share originates from N xation and how much from respiration. Nonetheless the interrelation between the rate of CO_2 and N xation rate could help investigate C consumption by N xation and therefore costs of g C per g N xed. For such a calculation di erent aspects such as srop species, the environmental conditions, as well as the growth stage[16] must be considered. So far a wide range (between 1.4 up to 8.5g C per g N) was reported (Liu et al. 2011).

However due to its high dependence on photosynthetic rates to cover additional energy costs, unfavourable changes in environmental conditions lead to a rapid drop in the availability of photosynthetic compounds and further to a shortage (or loss) in BNF (Mechtler 2012). This further accounts for a great variability in the xation rate in plants that perform BNF (Friedel et al. 2003 and Mechtler 2012).

Besides e orts to determine carbon costs for plant-BNF compared to mineral N uptake may be missleading since plants only take up 40-50% of N fertilizer applied and environmental consequences through leaching and costs for fertilizers are usually not included

[16]Currently there is an open debate on whether C decreases or increases with continuing growth rate of the crops (Liu et al. 2011).

(Cooper and Scherer 2012, 398 and Hawkesford 2012, 135).

Even though plants have to share plant generated energy through offering C to their symbiotic partners they are also gaining lots of advantages (e.g. higher survival rate in unfavourable conditions). Moreover this ability of accessing an additional/third N-source through BNF is barely found in other plant species (Hawkesford 2012, 135) and hence poses intrinsic potentials (Brady and Weil 1999). Such potentials include sound arguments for further promoting legume-based, sustainable farming systems. But they are also relevant for intercropping systems, extending cropping cycles and may even offer beneficial effects for subsequent crops in temperate zones (Liu et al. 2011 and Schipanski et al. 2010) by supporting the formation of soil N fertility (Liu et al. 2011). Especially in the humid tropics intercropping or rotaional cropping systems, which include nodulating legumes, are vital because in such regions there is often barely a market for N fertilizers due to high expenses and lacking infrastructure (Cooper and Scherer 2012, 404).

As mentioned before the ability of BNF is observed in a manageable number of plants, not just in soybean, but also in other grain legumes like lucerne and forage legumes, in some leguminous trees like *Leucaena leucocephala* and *Robinia pseudoacacia*, as well as the non-leguminous tree found in the tropics called *Parasponia*. These are all capable of forming a symbiosis with different strains of nitrogen-fixing bacteria (Cooper and Scherer 2012, 390; Liu et al. 2011 and McNeil 2010, 227).

Free living bacteria from the Rhizobium species can be found in cultivatable agricultural soil (Brady and Weil 1999, 514), but they are (to a different degree) host-specific and symbiosis only results from a mutualistic interaction between rhizobia and leguminous plants leading to a successful infection and resulting in the formation of a nodule (Brady and Weil 1999, 514; Cooper and Scherer 2012, 392; Fustec et al. 2010 and McNeil 2010, 229f.). What is noteworthy though is that most responding processes involving nodulation and N fixation, are regulated by the plant (through the rhizosphere) rather than by the bacteria (McNeil 2010, 230).

Furthermore not all rhizobacteria strains are equally capable of performing atmospheric nitrogen fixation, which might ultimately lead to variability in crop yield and thus pose a problem in agriculture (Cooper and Scherer 2012, 398). Therfore there is a possibility of bacterial strains being ineffective by forming a lot of nodules but fixing little amounts of nitrogen. At the same time that very same bacterial strain may be highly effective in combination with another host. This is a good chance that soybean, amongst other plants, may actively select the bacterial strain for a symbiosis (Cooper and Scherer 2012, 399 and McNeil 2010, 230f.).

Also certain kinds of Rhizobium species are more likely to be found in agricultural soil if speci c legumes have been grown at this location for several years. However this bacteria population may be too small to be e ective. If that is the case, or if legumes should be introduced to a new location, pre-assembled mixtures (inoculation) are purchasable, where either the legume seeds are coated or the bacteria strains are directly applied onto the soil (Brady and Weil 1999, 514).

Inoculation and related breeding efforts

Especially if soybean is cultivated on a eld for the rst time N_2- xing rhizobacteria probably is not present in su cient quantity or there may be less favourable strains in the soil. This is why it is advised to use seed inoculation with selected rhizobacteria strains (mainly containing- even though probably non-indigenous - *Bradyrhizobium japonicum*[17] (Brandstetter et al. 1993, 4; Mishra 2010, 219 and Schori et al. 2003)) in an attempt to increase the possibility of a successful symbiosis between rhizobacteria and soybean plants subsequently leading to nodulation and biological nitrogen xation. It is believed that rhizobacteria is generally able to survive in soil for roughly 10 years (Cooper and Scherer 2012, 398f. and Schori et al. 2003), but when using inoculation it should be avoided to expose the rhizobacteria to UV-radiation (Brandstetter et al. 1993, 4).

After having completed a cropping-cycle enhanced amounts of N- xing bacteria remain in the soil compared with previous quantities, although the population may decrease again if no suitable hosts are available for a longer period of time (Mechtler 2012). Lack of inoculation was reported to reduce yield up to 40%. This reduction was down to 10%, if inoculation was caught up with at the beginning of the growing period (Schori et al. 2003).

As indicated before there are various techniques available for inoculation some of which are described in further detail in literature as cited in McNeil (2010)[18], and also mentioned

[17] As McNeil (2010, 229) stated, Williems (2006) conducted a taxonomy to classify the *Rhizobium* species that is now generally accepted. It contains a category of fast-growing bacteria: *Sinorhizobium fredii* and *Sinorhizobium xinjiangense* (McNeil 2010, 229) (which was described to form *promiscuous nodulation* (McNeil 2010, 229)). Further, it is stated that bacteria of this very category also produces acid (Brady and Weil 1999, 514). The second category is one that contains bacteria which is slow-growing: *Bradyrhizobium japonicum, Bradyrhizobium elkanii* and *Bradyrhizobium liaoningense* (McNeil 2010, 229), which does not produce acid (Brady and Weil 1999, 514). Thirdly there are bacteria strains that are intermediate growing, such as *Mesorhizobium tianshanense* (McNeil 2010, 229).

[18] McNeil (2010) provides further literature suggestions in respect of this topic e.g.:

[Spaink, H.P. (2000) Root nodulation and infection factors produced by rhizobial bacteria. Annual Review of Microbiology 54, 257–288.

Zehner, S., Schober, G., Wenzel, M., Lang, K. and Göttfert, M. (2008) Expression of the Bradyrhizobium japonicum Type III secretion system in legume nodules and analysis of the associated tts box promoter. Molecular Plant-Microbe Interactions 21, 1087–1093.

in Brandstetter et al. (1993, 4). Also there are intensive breeding e orts to develop *promiscuous nodulating varieties* (Gwata et al., 2004, as cited in McNeil 2010, 230, 239, see footnote 17) of bacteria with increased microbial xation in both speci c environments and under more general/unspeci c conditions. These breeding goals have been targeted by selecting bacteria that responded well to inoculation or had undergone mutation, as well as introducing technologically engineered/altered bacteria. Another aim is to enhance the eld survival rate of bacteria and to induce nodulation of plants at a later date. By now there are numerous collections of bacteria of the Rhizobium species around the world, with research focussing on a successful inoculation of e cient and e ective bacteria strains which perform well under eld conditions (and under high competition) (see Table 12). Another goal is to maintain the population in the soil for a longer period of time throughout changing environmental conditions, because there have been results implying enhanced eld response of bacteria whenever a higher population is present and delivery mechanisms are improved. In addition enhanced quality control was suggested as an accompanying procedure (McNeil 2010, 230 ., 239).

But considering the e ciency (McNeil 2010, 230 and Schipanski et al. 2010) and the e ectiveness (Schipanski et al. 2010) for nodulation and xation, it is believed that these traits depend stronger on the bacteria strains than on the legumes (McNeil 2010, 230). Additionally the carbon cost for producing one gram nitrogen (g C/ g N) xed is also believed to be in uenced mostly by the rhizobia strain (Liu et al. 2011). The e ciency of N xation is thereby mainly in uenced by bacteria which di ers in certain genes (e.g. (Hup+) genes, which are responsible for hydrogen uptake) (McNeil 2010, 230). So far though trials aiming for yield improvements with altered rhizobacteria strains were insu ciently successful under eld conditions or lacked success in incorporating aimed traits into cultivars (McNeil 2010, 230).

Schipanski et al. (2010) further raised concerns that recent soybean varieties, compared to older varieties, have been discovered to be less e ective in avoiding ine cient rhizobial strains when soil N was available. The authors pointed out that intensive selection in high soil N environments have (intentionally or not) distinctively shaped current soybean varieties. Consequently this could have led to changes in the interaction between plants

Oldroyd, G.E.D. and Downie, J.A. (2008) Coordinating nodule morphogenesis with rhizobial infection in legumes. Annual Review of Plant Biology 59, 519–546.

Gwata, E.T., Wofford, D.S., Pfahler, P.L. and Boote, K.J. (2004) Genetics of promiscuous nodulation in soybean: Nodule dry weight and leaf color score. Journal of Heredity 95, 154–157.

Carroll, B.J., McNeil, D.L. and Gresshoff, P.M. (1986) Mutagenesis of soybean (Glycine max L. Merr.) and the isolation of non-nodulating mutants. Plant Science 47, 109–114.]

Table 12: Classification of Rhizobia Bacteria and Associated Legume Cross-Inoculation Groups

Bacteria		**Host legume**
Genus	Species/subgroup	
Rhizobium		
	R. leguminosarum bv. viceae	Vicia (vetch), Pisum (peas), Lens (lentils), Lathyrus (sweet pea)
	R. leguminosarum bv. trifolii	Trifolium spp. (most clovers)
	R. leguminosarum bv. phaseoli	Phaseolus spp. (dry bean, runner bean, ect.)
	R. fredii	Glycine spp. (e.g. soybean), Vigna, Cajanus
	R. etli	Phaseolus
	R. galegae	Galega
	R. lupinii	Lupinus, Ornithopus
	R. loti	Lotus (trefoils), Lupinus (lupins), Cicer (chickpea), Anthyllis, Leuceana, and many other tropical trees
Sinorhizobium	S. meliloti	Melilotus (sweet clover, ect.), Medicago (alfalfa), Trigonella, (fenugreek)
Bradyrhizobium	**B. japonicum**	Glycine spp. (e.g. soybean), Macroptilium, Vigna
	B. sp.	Vigna (cowpeas), Arachis (peanut), Cajanus (pigeon pea), Pueraria (kudzu), Crotolaria (crotolaria), and many other tropical legumes
Arorhizobium		
Photorhizobium		
Allorhizobium		

Source: (tables altered) Brady and Weil (1999, 515) and Cooper and Scherer 2012, 393.

and the N- xing microbes. As a result, so the assumption, soybeans have weakened their ability to restrict atmospheric nitrogen xation if a certain level of soil N is present at the same time. This however leads to the question of how well soybeans are still able to adopt regulating functions in N cycling dynamics (with BNF back feeding and suppressive regulations working inexact while soil N is available)? This trend is supported by results showing that winter annual legumes and perennial legumes, which generally haven t been targeted as intensively in breeding, do not show such tendencies in cash-grain rotations.

On the other hand, if soil fertility is rather low, nodulating soybean breeds were generally able to take up higher amounts of N than non-nodulating soybeans. Results suggest that soybeans grown in nutrient poor soil with declining N reservoirs are able to form symbiosis. Consequently nodulating varieties are still able to increase carbon circulation within soil and hence are also able to open up the accessibility of nutrients (Schipanski et al. 2010).

Enhanced C circulation on the other hand is likely achieved through increased root biomass, which enables plants to cover larger amounts of soil, making them more e cient in acquiring nutrients. But this trait is aligned with increased amounts of root C exudation, which in turn causes an increase in net N mineralization of soil organic matter pools. Mineralization of N from larger soil organic matter pools in turn may suppress BNF, concluding that a lot of the mineralization of inorganic N from such pools relies upon microbe activity (which itself largely relyies on e.g. temperature or soil moisture) and C availability and which further illustrates the importance of the C/N ratio. N loss on the other hand occur through denitri cation, volatilization, leaching and immobilization (Schipanski et al. 2010).

Further it should be noted that the formation of a symbiosis is a rather delicate process depending not only on a su ciently high phosphorus level (Brady and Weil 1999; Cooper and Scherer 2012, 390 . and McNeil 2010, 228) as well as su cient calcium, sulphur, molybdenum and iron supply (Brady and Weil 1999 and Cooper and Scherer 2012, 390 .), inoculant techniques, temporal precision and soil N (Salvagiotti et al. 2008), but also on other (environmental) impacts such as temperature (McNeil 2010, 227, 237 . and Zhang et al. 1995).

Environmental restrictions may e.g. entail insu cient soil water content (moisture (Soldati 1999, 677f.)), salinity, too high acidity (pH)[19], unbene cial physical soil structures (such as unsuitable texture and lack in aeration of the soil (Soldati 1999, 678)) or unbene cial temperature and fertility, as all of these factors assist in regulating microbial

[19]Which is why rather acidic soil should probably be limed in order to enhance the pH and thereby improve or maintain BNF performances of the rhizobacteria (Friedel et al. 2003).

activity in the soil (Cooper and Scherer 2012, 404 .). In addition herbicide or pesticide contents also interact with nodulation rates (Mishra 2010, 219 and Zarea 2010, 218). For instance positive infections and nodulation are more sensitive towards nitrate than ammonium (Cooper and Scherer 2012, 403). Hence symbiosis with Rhizobium bacteria are most e ective on soil that have high levels of essential nutrients (but not in toxic quantities) and do not have too low pH values, even though symbiosis with *Bradyrhizobium* is known to bear considerable acidity (Brady and Weil 1999, 514 and McNeil 2010, 238).

A variety of environmental stress factors also reduce N xation rates in soybean cultivation even though plants are less sensitive towards environmental impact than symbiosis or nodulation formation which react much sooner e.g. to salt stress, high temperatures, herbicides (McNeil 2010, 238f.) too high or too low pH values (Brady and Weil 1999 and McNeil 2010, 238f.), high soil moisture (see Chapter 3.1.2.12.11 on disease-resistance), or osmotic stress (see Chapter 3.1.2.12.4 on osmoregulation) (McNeil 2010, 238f. and Schipanski et al. 2010). Especially the plant habitat and conditions in the rhizosphere have been reported to a ect interactions between N- xing bacteria and host plants quite strongly (Friedel et al. 2003 and Cooper and Scherer 2012, 398, 404). Consequently creating more favourable conditions by taking measures to optimize, improve and promote yield performance of the host plants (Mechtler 2012 and McNeil 2010, 239) and establishing bacterial populations (Cooper and Scherer 2012, 398, 408) usually also lead to an improved N_2 xation rate and most likely to higher N residues for subsequent crops (except if such measures include applying large amounts of mineral N fertilizer, which of course suppresses nodulation) (Mechtler 2012 and McNeil 2010). Such measures also lead to higher inoculation successes (Cooper and Scherer 2012, 398).

How a symbiosis between soybean and bacteria is initiated through infection

In a symbiosis between N- xing bacteria and soybean the legume provides the N- xing bacteria with energy and carbon while the bacteria provides the host plant with N, mostly o ered as ammonium (Liu et al. 2011 and McNeil 2010, 230, 232). The process is initiated through exudates sent by legume seed coats or roots, which include glycones or aglycones from various avonoid subgroups, in order to attract Rhizobacteria. The bacteria responds in a more or less host-speci c way although details about correlations are not absolutely clear yet. Recent studies have shown though that *flotillins* play a major role in successful infections in nodulating crops (Cooper and Scherer 2012, 393-396).

A symbiosis between soybean and bacteria begins after Rhizobacteria successfully infects the legume root hairs, followed by the development of an infection thread and an infection of the cortical cells (Brady and Weil 1999, 514; Liu et al. 2011 and Mechtler 2012)

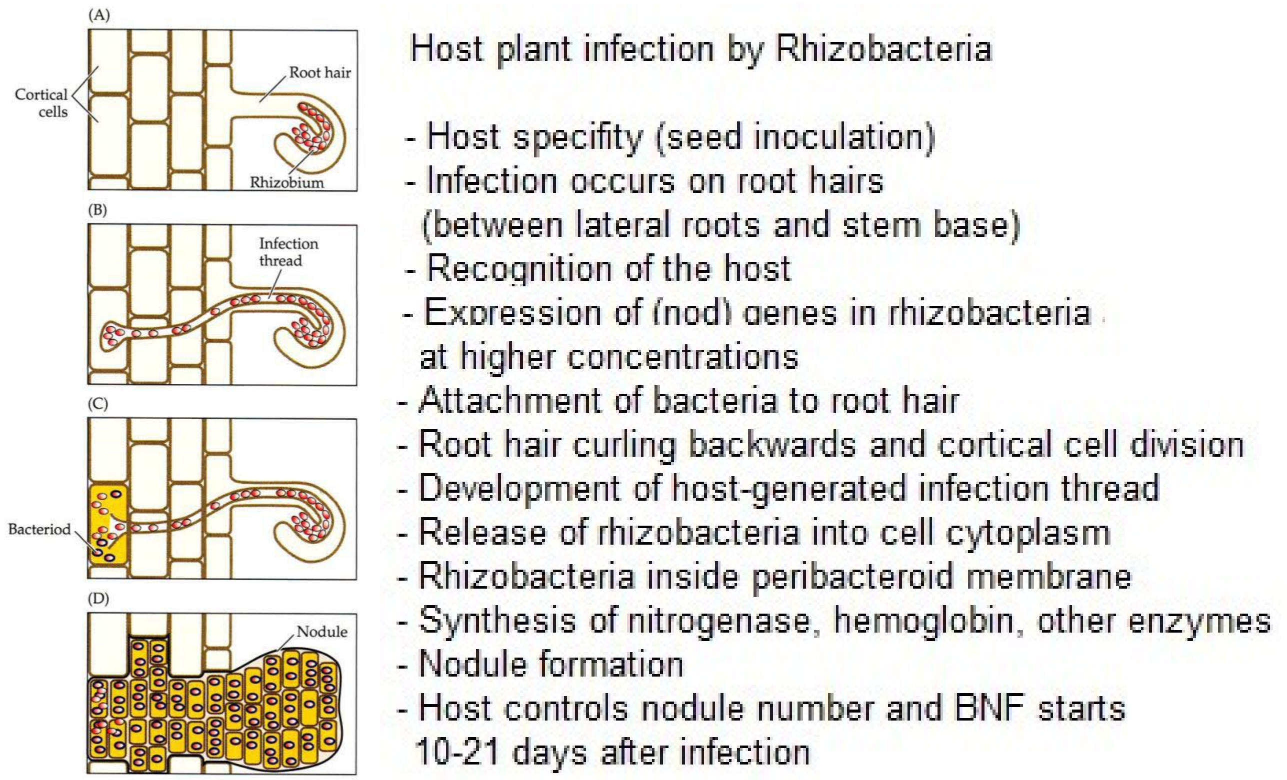

Figure 13: Infection of a legume with Rhizobacteria

Source: Epstein and Bloom (2005).

and after the tip of a root hair curls backwards. Through this process the root tissue becomes highly dividable and the formation of a compartment, the root nodule, starts in the outer cortex. In the nodules a fully functioning symbiosis is established after a *molecular dialogue* (Dénarié et al., 1993, as cited in Cooper and Scherer 2012, 393) with an exchange of substances, e.g. water or assimilates, take place as bacteria is now connected with the leading tissue of the host (Cooper and Scherer 2012, 393 and Mechtler 2012).

Inside such nodules the bacteria is enclosed in the form of bacteroids (McNeil 2010, 230). Soybeans possess speci c nodule structures in which several bacteroids are found within one host-derived peribacteroid membrane sac which regulates the ows between bacteroids and its environment (McNeil 2010, 230). The bacteroid uses sucrose, which is supplied by the plant, to convert this sucrose into organic acids. These subsequently serve as carbon source for the bacteroid. The energy provided by this carbon source is then used to x nitrogen (in the form of ammonia). As result ammonia in soybean plants is transformed into ureids in the nodules which in the following are returned to the plant. Ureides in soybean plants are then transported through the plant through the xylem to the above-ground parts of the plant (McNeil 2010, 232). It was also suggested that alanines (amino acids) are translocated from bacteroids to plants as well, which may be the reason for nitrogen- xing soybeans having less than 100% of ureides in their xylem (McNeil 2010, 232).

Another substance that may be stored in large quantities in soybean nodules is poly-β-hydroxybutyrate which can be broken down by bacteroids and is used to stimulate nitrogen xation. In the case of unfavouring environmental conditions (e.g. an occurrence of stress factors or enduring shading) this mechanism helps to avoid oxygen damage, as it ensures that bacteroids will not shut down nitrogen xation abruptly, and grants quicker regeneration of soybeans from shading as well (due to persistent nitrogen xation) (McNeil 2010, 232).

To sum it up, within nodules, the N- xation process takes place as atmospheric nitrogen (N_2) is reduced by an enzyme called nitrogenase (McNeil 2010, 228 and Mechtler 2012), an enzyme unique to N2- xing microorganisms (Broadley et al. 2012, 227). Nitrogenase is also obligate anaerobic - highly oxygen sensitive - (McNeil 2010, 230 and Mechtler 2012) and serves as a catalyst driving a reaction on which further leads the nitrogen molecule to splitting and - together with electron supply and energy - converting it into ammonia (Brady and Weil 1999, 512 and Liu et al. 2011).

Nodules therefore o er an ideal environment for the N xing process by providing 1) an oxygen di usion barrier, which is facilitated through intercellular air spaces to protect the nitrogenase against an exposure to oxygen (Fustec et al. 2010 and McNeil 2010, 230) and regulating the internal oxygen level to 3-30 nM (McNeil (2010, 230)) and 2) by synthesising an oxygen-binding haemoprotein (leghaemoglobin[20]), the oxygen carrier protein in the so-called *symbiosome* (Fustec et al. 2010 and McNeil 2010, 230), which consists of an enzyme complex built in most cases from molybdenum and - or in some cases only - iron (Brady and Weil 1999, 512; Broadley et al. 2012, 227 and Mechtler 2012) and sometimes vanadium (Broadley et al. 2012, 227).

This is why the inside of active nodules is white at the very beginning but changes to a red colour for most of their lifespan. Has a nodule reached the end of its active phase the colour starts getting brown accompanied by maceration. At this stage the host plant takes up all substances left, often leaving nothing behind but empty shells of former nodules (Mechtler 2012).

Amounts of atmospheric nitrogen fixation accounted for by BNF

The amount of N xed passes into three directions. One share is required by the host plant (which is a major bene t of the symbiosis) and some of this share may also enrich the site, as in the case of plant residues being left on the plot in order to decay. Another share may pass to non- xing plants that grow, e.g in mixed cropping systems (especially evident through the vast growth of associated grass species (see Chapter 3.1.2.4.1 on intercropping), through mineralization of nitrogen-rich constituents of root exudates or nodule residues that have become detached from legume roots and in smaller magnitudes also through mychorrhizal hyphae connecting legumes and non-legume plants. And the remaining share is immobilized by heterotrophic soil organisms. It is this share which may ultimately merge into soil organic matter (SOM) (Brady and Weil 1999, 517).

In general data referring to average N_2 xation rates of legumes range between 24 250 kg N ha^{-1}per season up to 340 kg N ha^{-1}per season. On the average though legumes produce 20 to 25 kg of shoot N which are xed per tonne of foliage dry matter (Cooper and Scherer 2012, 405f.), as can be seen in Table 13. Soybean is hence often stated to be able to x between 50-150 kg N per ha and year through BNF. Mairunteregg (2012, 28f.)) however referred to Heatherly and Elmore (1993), who reported soybean with a BNF rate ranging between 15 and 260 kg/ha^{-1} and year and who also assume that soybean is able to cover up to 75% of its N requirements through BNF from 10-14 days after emergence onwards and that BNF-derived N accounts for about 70% of biomass. Either way the rather

[20]Leghemoglobin is in its structure a very similar oxygen-transporter molecule as hemoglobin, which pigments human blood red when oxygenated (Brady and Weil 1999, 513 and Mechtler 2012).

large range of reported atmospheric nitrogen fixed is also a response to management and production related measures and environmental (Schipanski et al. 2010 and Salvagiotti et al. 2008) and ecological impact (which are described in the Section *Inoculation* further above) with contributing factors such as soil texture and above ground biomass (Mechtler 2012, see also McNeil 2010). In regards to soil texture a guarantee of a well functioning gas-exchange between the pores of the top soil and air layers near the soil surface should be especially focused on in order to ensure a good supply of atmospheric nitrogen to the nodules and a well functioning development of the symbiosis. For the same reason aggradations and encrustations of the soil surface should be kept to a minimum (Mechtler 2012).

Schipanski et al. (2010) and McNeil (2010, 228) further reported approximate calculations of soybean fixing between 50-60% of total N worldwide. However it was highlighted that the soybean would have a near neutral balance in respects to soil N (Salvagiotti et al. 2008 and McNeil 2010, 228)[21].

> Hence *"[...] it should not be assumed that the symbiotic systems always increase soil nitrogen. Only in cases where the soil is low in available nitrogen and vegetation includes strong nitrogen fixers would this be likely true"* (Brady and Weil 1999, 516, see also McNeil (2010)).

For instance a major problem that arises if soybeans are grown in order to increase soil N fertility is that most of the N fixed gets removed when all plant residues are taken off the field at harvest (Brady and Weil 1999, 516 and Liu et al. 2011). For example nitrogen conserved in seeds, and thus taken off the field, usually exceeds atmospheric nitrogen fixation rates from the soybean resulting in a decrease of mineral soil N (Salvagiotti et al. 2008). For these reasons (Brady and Weil 1999, 516) suggest substituting the term *nitrogen savers* for leguminouse crops whose N mostly becomes removed from the field instead for the term *nitrogen builders.*

The part of N fixed by legumes that stay in the soil therefore usually derives from roots, nodules or litter fall (Cooper and Scherer 2012, 406). If however the entire plant (or the majority of it) gets incorporated into green manure such as (from perennial the crop alfalfa or an annual crop like the hairy vetch), significantly increased amounts of soil nitrogen

[21] Further details on amounts fixed biologically by soybeans are given e.g. by Salvagiotti, F., Cassman, K.G., Specht, J.E., Walters, D.T., Weiss, A. and Dobermann, A. (2008) Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. Field Crops Research 108, 1–13. and Herridge, D., Peoples, M.B. and Boddey, R.M. (2008) Global inputs of biological nitrogen fixation in agricultural systems. Plant and Soil 311, 1–18.

Table 13: Amounts of biologically fixed nitrogen (BNF) in di erent crops.

host	symbiont	kg N/ha/yr	Source
Glycine max L	Bradyrhyzobium	50-150	Brady and Weil (1999)
Medicago sativa (Alfalfa)	Rhizobium	150-250	Brady and Weil (1999)
Vicia vilbosa (Vetch)	Rhizobium	50-150	Brady and Weil (1999)
clover, lucerne, saifoin (organically grown)		100-270	Friedel et al. (2003)
fava bean, pea, lupine, soybean		50-150	Friedel et al. (2003)

may indeed be built up and should also be accounted for in agricultural systems (e.g. for calculating fertilizer use or estimating the risk for environmental pollution) (Brady and Weil 1999, 516f. and Cooper and Scherer 2012, 406f., see also Chapter 3.1.2.4.1 on intercropping). Additionally, N from plant material in soil can also be increased by C rhizodeposition due to enhanced microbial activity (Cooper and Scherer 2012, 407).

Schipanski et al. (2010) also point out that the sources of N shift throughout the developmental stage of soybeans, hence BNF rates vary throughout the growing stages (see Figure 14). For example 86% of BNF was found during pod lling stage (with 2 kg perha^{-1} and day between R4 and R6 growth stages). If N fertilizer would be applied when combined N is about at zero or at very low levels, the N reserves in seeds would be responsible for whether the N fertilizer would lead to enhancing e ects or not (Cooper and Scherer 2012, 403). Depending on the physiological growth stage of the host plant (Liu et al. 2011), as well as the intensity in biomass production (Cooper and Scherer 2012, 403), BNF rates vary with peak values occurring between early owering and early seed- lling stages. Again this depends very much on the habitat and the species. Followed by this peak a dramatic decline or complete stop of N xation sets in during seed- lling when nodules start decaying and C supply is poor (Liu et al. 2011). But as a rule highest xation rates (and therefore nodule activity) are reached when the seed N reserves and mineral N (no matter from which source) are ready to be taken up in amounts that are high enough to initiate enhancement in biomass during the rst weeks after germination (McNeil 2010, 234).

In addition atmospheric nitrogen can also be taken up by foliar deposition (see Chapter 3.1.2.12.6 on foliar disposition). This atmospheric N derives mostly from recycled N fertil-

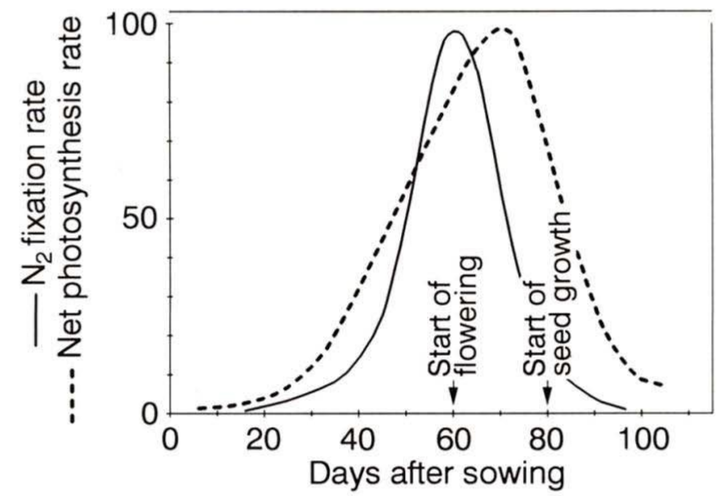

Fig. 7.9 Changes in rates of net photosynthesis and N_2 fixation during growth of cowpea. Relative values. (Based on Herridge and Pate, 1977.)

Figure 14: Change in N2 due to photosynthesis
Source: Marschner (1995).

izers, bruning, or factory emissions (McNeil 2010, 228) causing di culties in determining the share of total N_2 xed originating from BNF (Cooper and Scherer 2012, 398).

However opinions on methods to quantify the rate of denitri cation are contradictory. Especially on a global scale the quanti cation of the BNF rate is di cult to establish due to lack of su cient data (especially for non-legume xation rates). Additionally there is too much unreliable data on acreage growing legumes. Estimates on BNF inputs in agricultural systems on a global level should therefore be treated with care. They are generally stated to vary between 40 to 50 70 Tg N y^{-1} (Cooper and Scherer 2012, 389). Quanti cation techniques of measuring BNF also include direct estimation of the yield by using empirical crop models or simulations. Recent studies most commonly used methods by which N could be measured directly, as examples: the acetylene (C_2H_2) reduction/hydrogen increment assay, N di erence, 15N-labelling and ureide methods[22] (Liu et al. 2011). or an analysis of isotopic formations and relative abundance of ureides

[22]Further literature about these methods were listed by Liu et al. (2011) and include:

- Herridge D.F., Peoples M.B., Boddey R.M. (2008) Global inputs of biological nitrogen fixation in agricultural systems, Plant Soil 311, 1–18.

-Carlsson G., Huss-Danell K. (2008) How to quantify biological nitrogen fixation in forage legumes in the field, in: Dakora F.D., Chimphango S.B.M., Valentine A.J., Elmerich C., Newton W.E. (Eds.), Biological Nitrogen Fixation: Towards Poverty Alleviation through Sustainable Agriculture, Springer Netherlands, Dordrecht, pp. 47–48.

(Schweiger et al. 2012).

However these (precise) methods are time-consuming and expensive and also consider, most techniques for measuring legume BNF involve destructive sampling of either the plant or the soil structure. One exception is the acetylene reduction/hydrogen increment assay, with the disadvantage that it can only be used for a short period of time, which is rather unpractical, since the N xation rate is subjected to great uctuations throughout the growth stages. Thereby the measurement only gives valuable insights into a short moment (Liu et al. 2011). Also the methods just mentioned cannot o er valuable conclusions on how to predict N xation rates but rather merely give information on the status quo embedded in certain environments (Liu et al. 2011). Consequently e orts to determine carbon costs of BNF compared to mineral N uptake are misleading, further considering that plants only take up 40-50% of N fertilizer applied (Hawkesford 2012, 135 and Cooper and Scherer 2012, 398). Moreover environmental consequences, e.g. through leaching, are usually not included and neither are nancial costs for fertilizers (Cooper and Scherer 2012, 398).

However if mineral N (e.g. through applied mineral fertilizer) is used it in uences BNF by either suppressing or increasing BNF (as shown in Figure 15). An increase in combined N (=soil and fertilizer N) results in a distorted increase in total plant N. Only a relatively small amount of combined N shows positive e ects on N_2 xation rates considering the lag phase between root infection and the beginning of BNF (Cooper and Scherer 2012, 403). If there is a lack of nitrogen during the initial phase or the xation onset consequences would include negative e ects on the leaf area, which would have to reach a certain Leaf Area Index (LAI) value in order to be able to supply the forming nodules with su cient photosynthetic compounds (Cooper and Scherer 2012, 403).

Cooper and Scherer (2012, 403) stated that initial supplies of starter N mineral fertilizer applied at low rates would hence a ect the nodulation and total amount of N from xation in a positive way, but that high supply rates would have negative e ects such as a drastic decrease of nodulation and suppressed BNF. On the other hand there is also data available stating that even 20-40kg N ha^{-1} starter-N would already decrease both nodulation and BNF (Cooper and Scherer 2012, 403). Still it is very common to recommend starter N for soybeans as well as for other grain legumes (McNeil 2010, 234).

With increasing amounts of combined N nitrogenase activity, and thereby nodule activity, lowers, depending of course on species, genotype and form of N applied. For instance soybean reacts quite sensitive to high nitrate supply through an inhibition of nodule formation, but even though nodule numbers may decrease in such a scenario, the

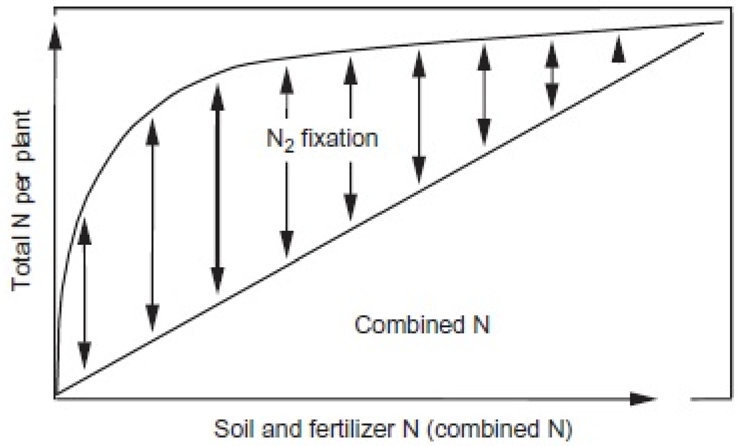

FIGURE 16.9 Simplified scheme of the relationship between N_2 fixation and N uptake from soil and fertilizer in nodulated legumes.

Figure 15: E ect of mineral N on BNF

Source: Cooper and Scherer (2012, 403).

shoot growth reportedly continues to increase (Cooper and Scherer 2012, 403). Such an increase in shoot growth in combination with too high N supply indicates a shift in N sources from symbiotic N to inorganic N. In addition results suggest that a peak in the N content measured in the shoot occurs at the same time as nitrogenase enzyme reaches its maximum activity. This however is not the case when the plant reaches its maximum dry weight. Cooper and Scherer (2012, 403) therefore conclude that the dry matter production is source-limited through the photosynthate supply when BNF reaches its peak. Consequently BNF may have higher priority than further plant growth.

McNeil (2010, 240) came to a similar conclusion and stated that plants whose sole N source was BNF might have to use a major share of initially produced nitrogen to further develop the symbiosis, which consequently could lead to lack of nitrogen and a lower yields. However positive e ects of BNF in agricultural systems are non-controversial, as nitrogen xing species are able to increase the nitrogen content in soil signi cantly over a longer period of time. This may also have bene cial e ects on subsequent non- xing species which in turn are incorporated through an intercropping system (Brady and Weil 1999, 514 .).

But as soon as mineral forms of N (such as ammonium) in the soil are available for plants an internal feedback mechanism would set in and would ultimately trigger a suppressive e ect inhibiting BNF and nodulation (Brady and Weil 1999, 515 and Schipanski et al. 2010). This suppressive e ect furthermore leads plants to preferentially take up the easier accessible nitrogen from soil (e.g. from fertilizers) as soon as it is available, even if a symbiosis has successfully been established before (Brady and Weil 1999, 515). Hardarson and Atkins (2003, as cited in McNeil 2010, 239) for example point out the potential for breeding nitrogen-tolerant N- xing cultivars.

Although, according to Schipanski et al. (2010), this suppression of N xation by soil available N was only secondary, with the soil texture being much more relevant and soil inorganic N having the strongest negative correlation with nitrogen that was xed. Moreover soil inorganic N would be an excellent indicator to predict % N by xation (Schipanski et al. 2010). In any case such suppressive feedback loops would further conclude that plants would also have less assimilates to support N- xing bacteria. This would consequently explain why the share of BNF decreases despite successful symbiosis as soon as arti cial N fertilizer is readily available. Countermeasures to this dilemma are stated to include well planned crop rotations (Mechtler 2012).

Foliar fertilization

Soybeans are also able to take up gaseous nitrogen and urea applied as foliar disposition regulated through stomata. Interestingly an application in this form does not lead to a longterm decrease in BNF, but it can a ect - and be a ected by - root N uptake (McNeil 2010, 233). Foliar uptake of gases has gained much interest and attention since air pollution is rising and the uptake rates may be rather high depending on climatic conditions. For example agriculture has been estimated to cause a share of 80% of atmospheric ammonia (NH_3) emissions in Europe and the US. Research was conducted to create application methods for organic materials in order to reduce these emissions (Eichert and Fernández 2012, 71f.). But foliar fertilization is also gaining increasing attention especially in agricultural systems in environments with restricted soil nutrient availability (especially with nutrients that are limited in phloem mobility such as Ca, B, Zn, Fe or Mn) (Eichert and Fernández 2012, 79).

The estimated share of nitrogen provided through foliar disposition in the year 1995 was 103 Tg N on a global level, but will possibly increase (up to 195 Tg N per year in 2050). Such amounts are further estimated to represent abount 16% of total nitrogen uptake by plants on a global level. According to a model by Sparks (2009, as cited in McNeil 2010, 227), either NO or NO_2 become nitrite or nitrate inside the apoplast in the leaves. In the cytoplasm the nitrate is then transformed by nitrate reductase to nitrite, which is ultimately transformed into NH_4^+(ammonium) and subsequently converted into glutamine in the chloroplasts. Atmospheric NH_3 (ammonia) on the other hand is transformed into NH_4^+. This ammonium is further converted by glutamine synthase to glutamine (in the cytoplasm or the chloroplast) (McNeil 2010, 233). Moreover McNeil 2010, 233 points out that late application of foliar nitrogen may be able to balance out some loss in N- xation and may further support increasing yields.

3.1.2.9.2 Nitrogen in different low-input, non-livestock integrated agroecosystems/organic agroecosystems Especially if soybean yields are intended for human consumption, high protein levels are needed (see Chapter 3.1.4 on processing), but this requires greater nitrogen levels (see Chapter 3.1.2.12 on agronomic breeding targets). Apparently though, in organic farming agroecosystems, no synthetic mineral fertilisers are authorised. As a result N inputs are heavily depending on BNF and other forms of atmospheric nitrogen xation. A successful and e cient symbiosis is consequently crucial in low-input systems (Friedel et al. 2003 and Schweiger et al. 2012). Furthermore, in agro-ecosystems in general but especially in organic farming, a long-lasting supply of nutrients needs to be established (Fustec et al. 2010).

Subsequently legumes which are incorporated in rotations or intercropping systems (mostly with Fabaceae) o er bene ts (such as maintaining or even increasing soil organic N through BNF) especially if applied in low-input agro-ecosystems (Fustec et al. 2010; Mechtler 2012 and Schipanski et al. 2010). Therefore subsequently grown non-legume crops, or plants grown in association with nodule forming legumes, may equally gain access to this renewable resource of N without being able to form a symbiosis by themselves (a process called rhizodeposition (Fustec et al. 2010)). Clearly though the degree to which an associated crop bene ts from an association with a nodulated legume in a mixed stand depends on the extent in which the legume is able to perform BNF, or rhizodeposition by i) the decomposition rate of the legume residues and subsequently the amounts of mineral N released (Cooper and Scherer 2012, 404f. and Fustec et al. 2010) or ii) though root exudating soluble nitrogenous compounds (Fustec et al. 2010). In addition grain legumes mostly meet dual purposes by conserving soil organic N and producing animal feed as well as comestible goods (Mechtler 2012).

3.1.2.10 Harvesting time, methods, yield and weed Harvest is generally performed with a combine harvester (see Figure 16). In regards to weed populations in soybean this mechanization - when used repeatably- also leads to a selection pressure through providing optimum conditions for seed dispersal, and for a number of weeds which were

Figure 16: Impressions of a soybean harvest

The pictures show impressions of a soybean harvest and the sample collecting at an experimental site run by the Chamber of Agriculture Upper Austria in 2014.

able to adapt (Murphy and Lemerle 2006).

Soybean should be harvested when the soybean stand has lost all leaves and has gained a brown colour (Brandstetter et al. 1993, 7, see Figure 17 and 18). Depending on the cultivar and the maturity group of the soybean, as well as on climate and region, harvest in Austria is usually performed between mid-September to mid-October (Pistrich et al. 2014, 56f.). In favourable locations in Switzerland harvesting time is during early September (Schori et al. 2003).

An optimum harvest time can be identi ed by slightly shaking the pods. If the seeds are producing a sound as they wiggle in the pods harvesting time has arrived. A more scienti c approach to determine the ripening stage of the seeds is to measure the moisture content of the seeds, which should range between 14-18% (Pistrich et al. 2014, 56f.) or 18-16% (Diepenbrock et al. 1999, 250) to indicate harvest. An optimum harvest date also helps to keep costs down because if the moisture content is too high, seeds would need additional drying.

An advantage of soybean stands is that they are relatively insensitive towards delayed harvest dates (e.g. due to rainy weather) (Pistrich et al. 2014, 56f.). An optimum moisture content to guarantee storage capability is 14% H_2O and maximum impurities should not exceed 2% (Diepenbrock et al. 1999, 250). In Austria 000-varieties are usually harvested 14 to 20 days earlier than 00-varieties (Pistrich et al. 2014, 56 .). Furthermore in order to minimize yield loss the mower of the combine harvester should be put as near to soil surface as possible (Brandstetter et al. 1993, 7 and Diepenbrock et al. 1999, 250) and should not exceed a cylinder speed of 500 rpm (Diepenbrock et al. 1999, 250).

In addition it should be noted that harvest dates are correlated with the cultivar used (and maturity group), as well as with the sowing date and environment conditions. It should be noted that e.g. environmental impact in uence the developments of the weed

Figure 17: Not fully ripened soybean plants

Not fully ripened soybeans detectable through more greenish than brownish stem-color and high water content. Little weed infestation on an experimental site in Upper Austria, supervised by the *Boden.Wasser.Schutz.Beratung Oberösterreich*, 2014.

Figure 18: Ripened soybean plants

Ripened soybean plants in autumn morning dew with weed infestation in the background on an experimental site in Upper Austria supervised by the *Boden.Wasser.Schutz.Beratung Oberösterreich*, 2014.

population as well. As already pointed out in Chapter 3.1.2.8 (on competitiveness against weeds), weed populations have perfectly adapted to the conditions of the crop species and the conditions of the production system in which they may be found. Consequently developmental timelines, plant height or ripening times of the seeds may match strikingly well (Murphy and Lemerle 2006).

3.1.2.11 Diseases So far there are barely any pests in soybean cultivation in Austria that cause severe economic/yield loss. On a global level insect pest infestations from *Aphis glycines, Heterodera glycines* (Liu et al. 2008; Österreichische Arbeitsgemeinschaft für integrierten P anzenschutz 2013, 9 and Soldati 1999, 682) and *Anticarsia gemmatalis* are posing serious threats (Österreichische Arbeitsgemeinschaft für integrierten P anzenschutz 2013, 9). Other pests have been reported to be *Agriotessegetis* (Haberlandt 1878, 101) and leaf miners (especially if their larvae feed on nodules, pod or stem borer pests (Mechtler 2012; Olechowski and Upfold n.d.; Singh G. and Shivakumar 2010, 35f. and Schori et al. 2003). Leaf defoliation or an infection of bean pod mottle virus may also occur after infestation with overwintering bean leaf beetles (*Cerotoma trifurcate*) (De Bruin and Pedersen 2008).

Bio-control with bene cial insects or natural enemy microbes, which parasite pests (*biocides*), has recently gained importance as a method to control pests, weeds and diseases as they are considered to cause less pollution. Moreover there are very few insect-resistant cultivars. What should be emphasised though, is that there are a number of measures in pest management that farmers can employ to improve plant health and reduce, or even prevent, infestation rates through crop management in the rst place (Liu et al. 2008).

Soil texture for instance (more speci cally soil moisture and aeration) have been reported to in uence plant pathogens. Also ner-textured soil are thought to be connected to higher susceptibility in stem and root pathogens (Schipanski et al. 2010). The soybean itself may also serve as vector for diseases, pests and pathogens which is why crop rotation systems are of such striking importance (see Chapter 3.1.2.7 on crop rotation and weed-control). Crop rotation systems are of special importance when dealing with pest and disease infestations that are di cult to manage otherwise. One e.g. is *Sclerotinia sclerotiorum* (Sclerotinia stem rot, see photograph 19) (Brandstetter et al. 1993, 6f.; Liu et al. 2008; Singh G. and Shivakumar 2010, 35f. and Unsleber 2011) which is also known in rapeseed and sun ower (Schori et al. 2003) and should therefore be targeted particularly in regions, in which rapeseed and soybean are increasing in the cropping cycle. Furthermore damage caused by *Sclerotinia sclerotiorum* depends not only on the portion

Figure 19: *Sclerotinia* on soybean.

The photograph was taken on an experimental site of *Kärntner Saatbaugenossenschaft reg. Gen.m.b.H.* in Carinthia, 2014.

of killed population, but also on how quickly individual plants die compared to how fast they develop their reproductive organs (Liu et al. 2008). Infestation with *Sclerotinia sclerotiorum* is particularly problematic because breeding for resistance is di cult and has not yet o ered satisfactory ndings (Schori et al. 2003).

Other known diseases include *Pseudomonas syringae, Peronospora manshurica* (Brandstetter et al. 1993, 6f.; Olechowski and Upfold n.d.; Schori et al. 2003 and Singh G. and Shivakumar 2010, 35f.), *Phytophthora* root rot (Liu et al. 2008); *Septoria* leaf spot (Soldati 1999, 81); yellow-mosaic virus (Singh G. and Shivakumar 2010, 35f.; Soldati 1999, 682 and Olechowski and Upfold n.d.), soybean mosaic virus, soybean rust and brown rot (Singh G. and Shivakumar 2010, 35f. and Olechowski and Upfold n.d.).[23]

Generally pest and disease management and prevention techniques may be accomplished through agronomic crop cultivation procedures. This is done by applying biocides or practising intercropping and e ective crop rotations in order to compose diverse environments which make it more demanding for pest to adapt. Other options include breeding e orts on a genetic level in order to enhance pest and disease resistant traits (Jannik et al. 2001).

It should be noted though that enhanced breeding success in resistance of genotypes e.g.

[23] More detailed information on various kinds of diseases in soybeans include especially [Hartman, G. L., Sinclair, J. B. and Rupe, J. C. (1999): Compendium of soybean diseases. 4th edition, American Phytopathological Society: St. Paul, Minnesota].

towards fungal pathogens also come with trade-o s (see Chapter 3.1.2.12 on agronomic breeding targets). In this particular case described by Jannik et al. (2001) breeding success for more resistant genotypes against fungal pathogens came along with a reduction in the ability to undertake mutualistic associations with vesicular arbuscular mycorrhizae as well as with the ability to avoid infections through pathogenic fungi (Jannik et al. 2001).

3.1.2.12 Breeding targets related to agronomy

3.1.2.12.1 Yield and Yield stability In respect of agronomic traits, rst and foremost soybean breeding goals include improvements on yield performance and yield stability (Diepenbrock et al. 1999, 248f.; Liu et al. 2008; Schuster et al. 2000 and Soldati 1999, 673), which may have something to do with yield having the greatest impact on producers net private income (Liu et al. 2008). Therefore it is vital to maximise yields in a cost e cient way, e.g. without enhancing input costs (De Bruin and Pedersen 2008).

Yield is the product of an interaction between a changing environment and genotypes (Liu et al. 2005 and Liu et al. 2008) and is an important indicator. Hence, commonly used categories to determine reproductive growth include a number of traits (i.e. yield components), such as the number of plants per unit area, pods per node, nodes per plant, seed weight, seed size or total biomass production (Liu et al. 2005 and Jannik et al. 2001). Total biomass production is considered particularly in environments with high weed pressure, since weed competes with the crops stand over nitrogen and N limitation may result in a shift from grain yield to enhanced straw production in soybean stands (Jannik et al. 2001).

With respect to yield stability, positive developments have been registered in connection with an adapted reaction to daylength and temperature (Diepenbrock et al. 1999, 248f.), as well as chilling tolerance (Soldati 1999, 673). Results of Jin et al. (2010). also suggest tight connections between yield stability and stable pod production, pod survival, improved seed number per pod and enhanced yields.

In China, the most contributing factor for improved soybean yield was established to be seed number per plant (Jin et al. 2010) or per land area, as well as pod number (Liu et al. 2005). Selection on seed size was suggested as additional selection criterion for enhanced yield genotypes, since signi cant positive correlations were observed especially in high yielding, early- and medium maturing genotypes (Liu et al. 2005). However, contradicting results stated that seed size would be a rather stable trait, independent of pod position within the plant (Jin et al. 2010 and Liu et al. 2005), but connected to the plant s response towards drought stress (Liu et al. 2005).

Generally though, seed size in current research is not considered to be a valid yield enhancing trait in soybean breeding (Jin et al. 2010 and Liu et al. 2005), whereas there remains to be a clear focus on higher numbers of seeds and pods per plant (Liu et al. 2005 and Schuster et al. 2000). In reverse, signi cantly higher numbers of pods and seeds in high-yielding genotypes compared to low-yielding genotypes re ect that selection in these traits have been introduced quite some time ago (Liu et al. 2005).

Apart from the in uence of a chosen soybean genotype, yield is also positively correlated with year-interactions[24] (Jin et al. 2010), resulting in response to site-speci c aspects such as soil characteristics, cropping patterns, as well as the sum of crop producing management practices (Uri 2000) and site-speci c limitations to N_2- xation rates (Mechtler 2012).

This is why profound knowledge of general plant requirements, plant management systems, physiological characteristics and selection of suitable soybean cultivars according to the locations are of the utmost importance (Jin et al. 2010 and Liu et al. 2008, see Chapter 3.1.2 on crop production).

Therefore, even though a theoretical biological limit for soybean yield was estimated to be 8 000 kg per hectare (Specht et al., 1999 as cited in Cooper 2003) maximum yields are most likely achieved in highly productive environments (Liu et al. 2005) and according to Cooper (2003) are likely to be limited through seeding rate, row spacing or lodging barrier.

However, there are certain plant characteristics that are associated with high-yielding genotypes. Such phenotypical traits include a vertical leaf disposition in order to allow high assimilation capacity, as well as a canopy architecture which o ers high re ective characteristics. Furthermore, the stem should be silm, short and growth should be terminated in an early stage, to allow maximum seed production capacity as well as low interplant competition (Liu et al. 2005).

Moreover, soybean seed yield is also the product of total biomass and Harvest Index (HI) (De Costa and Shanmugathasan 2002), leaving two main possibilities to enhancing grain yield: either by improved Harvest Index or by enhancing dry matter accumulation (Liu et al. 2005).

Though genetic improvements proved not to be able to signi cantly increase soybean Harvest Index. Also, during a two-year study period (Liu et al. 2005) found no evidence for altered Harvest Index, concluding that modern cultivars improved predominantly in

[24] Climate conditions are commonly referred to as *year interaction factor* (Uri 2000).

dry matter production which according to the authors was especially enhanced during seed filling stage due to positive correlations to LAI at R5 developmental stage and yield (Liu et al. 2005). Similarly, Kumudi (2002, as cited in Liu et al. 2005, see also Schori et al. 2003) pointed out that total dry matter accumulation seems to be a more valuable contributor to yield increase than Harvest Index, but that Harvest Index itself should be paid particular attention when selecting higher yields in early maturing genotypes (Acquaah, 2002, as cited in Liu et al. 2005).

Likewise Jin et al. (2010) stated that modern cultivars in China had increased photosynthetic rate, dry weight and Harvest Index, while having a decreased leaf area index (LAI).

Generally speaking though, yield and yield stability are reported to be influenced by a huge variety of factors and plant traits, as shown in Figure 20, which is why most of the subsequently described breeding goals also enhance yield or yield stability directly or indirectly. This Figure also illustrates, how some traits are negatively correlated (e.g. crude oil/protein content). Hence, some characteristics may be improved, while simultaneously others suffer negative outcomes, concluding that it is not possible to improve all traits/breeding goals at the same time (Li et al. 2014).

What should be kept in mind is that an improvement of particular traits depends on the genetic variation present (see for instance Hardarson and Atkins, as cited in McNeil 2010, 239).

3.1.2.12.2 Environmental impact on soybean Results showed that environments generally have great effects on initial plant growth patterns of soybeans. Great effect of environmental impact was also documented on seed size in early maturing soybean lines, whereas it was lacking or non-significant in later maturing soybean genotypes. Seed size is therefore tightly correlated with environmental conditions. This correlation was illustrated for example in trials conducted in Minnesota by (Jannik et al. 2001), who stated that early maturing soybean lines produced larger seeds than late maturing varieties. However, these results were observed more frequently in experimental sites which were situated in more northern latitudes as well as during years which were marked by shorter growing periods. The authors therefore concluded that the results were depending stronger on environmental influences rather than on internal environmental-independent mechanisms.

Additionally, significant environmental impact on later maturing lines could be explained by a decline in temperature and shorter photoperiod when entering the plant

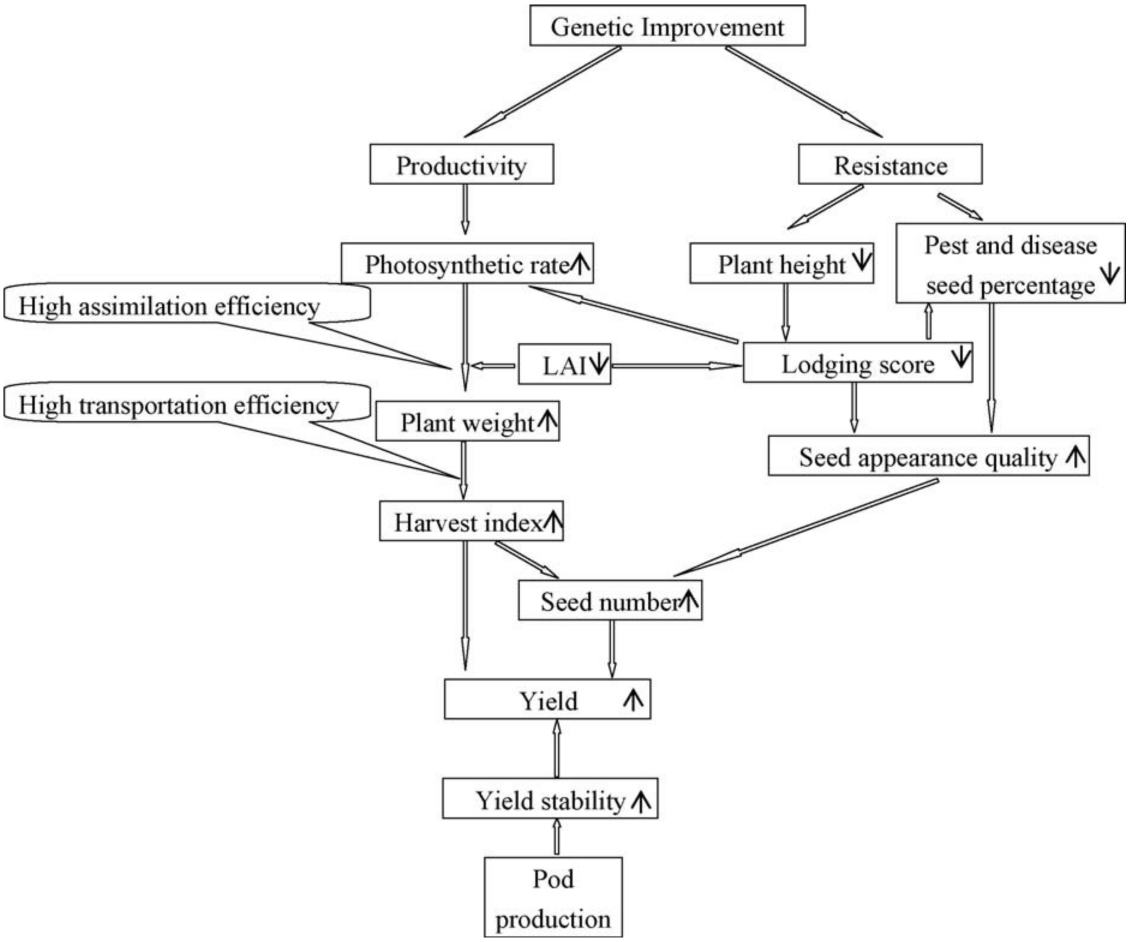

Figure 20: Traits associated with genetic improvements in yield and yield stability in northeast China between 1950 and 2006

Source: Jin et al. (2010). Upward pointing arrows signal improvements, whereas downward pointing arrows signal decreases.

maturity stage. During this particular developmental stage, later maturing varieties run greater risks of not being able to complete seed lling, resulting in decreased seed size. This further suggests great dependence of seed size on environmental conditions rather than on genetic determination (Jannik et al. 2001).

Results from a trial on simulated weed pressure on early maturing soybean genotypes in eastern Austria conducted by Vollmann et al. (2010), on the other hand, illustrated how early maturing genotypes showed less yield loss subsequent to enhanced weed pressure in comparison to later maturing varieties. Moreover the ndings of the authors revealed high correlations between yield loss and weather conditions, as lower temperatures in early May and June lead to delayed closure of the canope of the soybean stand, subsequently promoting weed growth.

Another report further con rms this tendency illustrated by the examples given above, stating highly signi cant environmental-year interactions in soybean yields assessments in Chinese growing periods between 1950 to 2000 (Li et al. 2014). In this assessment it was pointed out that mean monthly temperatures proved to be most in uencial on the 100-seed weight and crude oil/protein contents. In addition, soybean trials run in Austria within years with low precipitation rates lead to faster cessation of photosynthesis within soybean plants. Such changes with respect to photosynthesis supply consequently lead to shorter plant height, compared to years with high precipitation rates. In years with high precipitation rates however, higher water availability resulted in elevated crude seed oil content (Vollmann et al. 2008, 320).

Phenotypic soybean traits are therefore in uenced by factors such as climate and geography. Besides, it was suggested that environmental impact factors had even greater in uence on plant trait variations than e.g. soil constitution and longitude. Even though the report concluded that soil properties had the greatest impact on variation in crude protein content (seed quality), the 100-seed weight, plant height and abiotic impact was also signi cant. Besides, abiotic stress in uenced the crude oil content itself. Moreover, the 100-seed weight was also strongly a ected by longitude, whereas latitude was stated to be most in uencial on plant height. An elevation in sea level on the other hand reportedly altered the 100-seed weight as well as the crude oil content (Li et al. 2014).

In contrast, Vollmann et al. (2008, 320) point out that, when genotypes are grown in one particular region, thousand seed weight is mainly determined by genetic constitution and that heritability would explain 80 to 95% of the protein- and oil contents. Similarly, Li et al. (2014) concluded from their evaluation, that environmental determinants were able to explain up to 40% of the variance in traits such as 100-seed weight, plant height and the crude protein/oil content. Some traits however, for example crude protein content or seed weight, would be stronger affected by heritability than by environmental exposure. According to the authors, traits with greater sensitivity towards environmental conditions include seeds per pod and pod number per plant. In addition they emphasised that crop management techniques such as the choice of planting dates or planting densities would be equally important (Li et al. 2014).

3.1.2.12.3 Chilling tolerance (not freezing damage!) and environmental stresses

A Swiss breeding program to enhance chilling tolerance obtained its plant material predominantly from a Swedish breeder called Swen Holmberg, whose breeding material originated from the islands Kouriles and Sakhaline, as well as from northern regions of Hokaido. These different parts of the world are all characterised by cool, foggy and moist climates. Consequently soybean seeds originating from these locations have adapted to harsher environments, singling them out as ideal breeding material for trials aiming for enhanced chilling tolerance above latitude 45°N. The enhanced chilling tolerance of these specific seeds is rooted in their ability to adapt to day length, even though, as a result, they may also show higher tendencies in pod shattering before harvest (Schori et al. 2003 and Schori et al. 2005, 43).

A main feature of chilling tolerant genotypes is its asynchronous flowering pattern, which is responsible for delayed flowering between main/inner flowers and non-main flowers which are sitting on stem sides. These non-main flowers are mostly initiated 10 days after main flowers and therefore show some time delay. This flowering over a longer period of time, combined with spatial variation (main and non-main flowers), enables the plant to compensate a rather sudden decline in main flowers due to chilling events. Despite this positive aspect this characteristic is also correlated with delayed ripening. In contrast genotypes with synchronic flowering patterns lack this plasticity, but may ripen earlier. Moreover, the synchronised-flowering varieties are also reported to produce more sterile internodes and show greater susceptibility/sensitivity towards cold/chilling damage (Schori et al. 2003 and Schori et al. 2005, 44).

Generally, damage caused through cold temperatures may be recognised by stunt growth, reduced plant height, delayed plant development and may result in extremely high yield loss (observations in China indicated loss up to 35%) (Liu et al. 2008). The habitus of soybean which suffered cold/chilling damage relies very much on the photoperiod and the temperatures, because phenology (and as such growth characteristics) is strongly influenced by multiple biochemical pathways on a whole-plant level (Setiyono et al. 2007).

However, the severity of chilling event-impact is very much related to the developmental stages of the plant. Concerning physiological cold damage for instance, the most critical period starts 15 days prior to owering and lasts until early owering stage. During this period of time the critical threshold temperature is 17.8°C (in contrast to 15.8°C in the seed- lling stage) (Liu et al. 2008).

To quantify genotypic response of soybean towards chilling events, Schori et al. (2005, 43f.) created a model that records all accumulated negative temperatures below 18°C in order to register duration and intensity of chilling events and helps matching the data to developmental stages of the plants. Subsequently, chilling tolerant parenting lines should be identi ed.

Another cropping management strategy in cooler areas is to enhance the population density, in order to select cultivars with lower leaf area (Jin et al. 2010), since research conducted in Switzerland revealed that a) an adaption to cooler environments would include a reduction in foliage and b) that crosses with the lanceolate leaves, which lie on the *ln* allel, do not a ect yield. Hence, phenotypic selections are possible and there are no trade-o s between cold/chilling tolerance and yield (Rotzler et al. (2009)).

3.1.2.12.4 Osmoregulation and osmotic adjustment under drought conditions Water stress may be caused either by a surplus of water (causing e.g. waterlogging) or by a lack of water (causing e.g. drought stress). In most cases though, water stress describes a situation of insu cient water supply (Shao et al. (2009)).

According to Liu et al. (2008), an enhanced content in the plant hormon abscisic acid (ABA) is one of the rst, most sensitive and discrete indicators to water stress in both roots and shoots. Generally, as a reaction to drought stress, roots maintain to grow, while shoot organs above ground show reduced growth and thus enhancing the dry weight or root/shoot ratio (Liu et al. 2008 and Shao et al. 2009).

In soybean production, adequate water supply (and distribution) during the vegetative plant stage helps to achieve su cient biomass, which is necessary to reach high seed yield. Moreover, ceasing vegetative growth was strongly related to drought events (Shao et al. 2009) with plant growth showing the greatest positive reaction towards irrigation while su ering water shortage, wheras pod- lling stage did not respond in such a powerful way (De Costa and Shanmugathasan 2002).

Therefore, lack of precipitation is a major constraint on increasing yields in soybean production (De Costa and Shanmugathasan 2002, Purcell et al. 1997, Shao et al. 2009) that further leads to negative impact on seed weight (Li et al. 2014) and N_2 xation

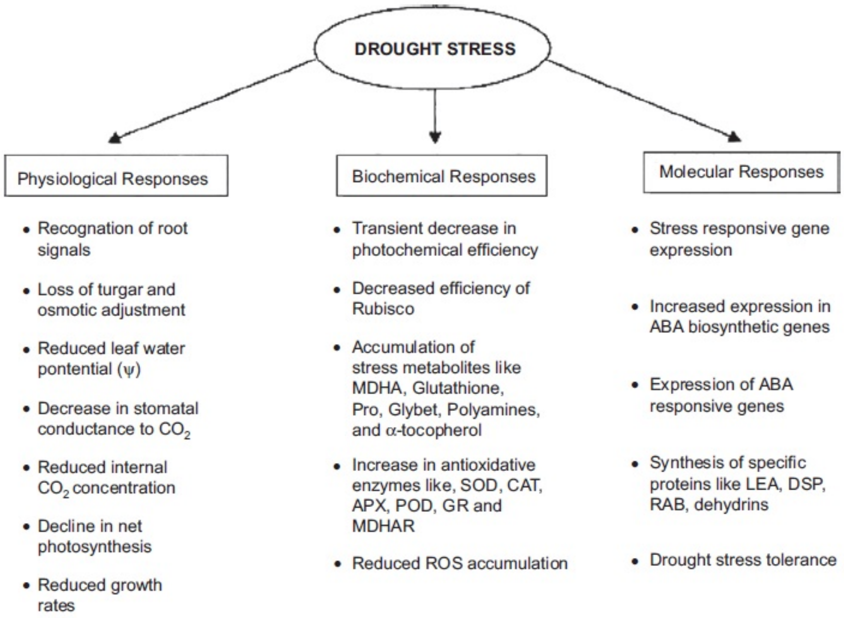

Figure 21: Physiological as well as molecular reasons for drought stress tolerance

Source: Shao et al. (2009).

rates (Purcell et al. 1997). Even though Haberlandt (1878, 97) discovered quite high tolerance towards drought when experimenting with soybean in Dalamita. Therefore it is important to understand assimilation, translocation and remobilization processes which are in uenced by drought stress, in order to improve responses such as yield loss (Purcell et al. 1997).

On cell level, turgor is essential for stomatal regulation and subsequently photosynthesis. The regulatory mechanism is called osmotic adjustment, which sustains turgor pressure and simulataneously reduces the leaf osmotic potential. During drought stress however, leaf osmotic potential decreases and other biochemical and physiological processes are being reduced. Consequently, respiration translocation, ion uptake, nutrient metabolism, carbohydrates, hormones and other responses (see Figure 21) are negatively e ected. Therefore, turgor maintenance is crucial in enabling plants to endure water stress (Shao et al. 2009).

Similarly, Liu et al. (2008) reported soybean cultivars with small sized seeds to maintain longer stomatal opening, combined with faster stomatal closure at drought stress events. This would consequently result in genotypes with increased tolerance towards drought.

Waterlogging

As mentioned before, waterlogging may also lead to water stress. In contrast to drought stress, accessibility of su cient oxygen poses a key factor in maintaining nitrogenase activity within the roots. Through this process, nitri cation in anaerobic soil is restricted (Rhine et al. (2010) and Schipanski et al. (2010), see also Marschner 2012). General plant phenotypical traits ascribed to waterlogging tolerance include an immediate development of adventitious roots as well as formation of stem aerenchyma. Flooded soybeans were reported to have adapted root architecture and maintained nodules (Rhine et al. 2010).

Subsequently, legume nodules and plants capable of biological nitrogen xation (BNF, see Chapter 3.1.2.9.1) may be particularly sensitive towards waterlogging compared to non-BNF plants (Schipanski et al. 2010).

Similarly though, soybeans ability to nitrogen xation, and in further consequence soybean yields, are also negatively a ected after su ering insu cient water supply. Drought events therefore cause similar e ects as ooding events (Purcell et al. 1997).

But as trials revealed, most soybean cultivars did not su er crop injury when ooded for 48-96 hours and showed greatest yield loss when waterlogging occurred at R5 stage (yield loss of 20-39%, compared to control), whereas least damage occurred at V5 stage. Some studies have shown that ooding tolerance is a genetic feature, which is already labelled in isolines (Rhine et al. 2010).

Water stress during different developmental stages

Liu et al. (2008) listed three processes leading to drought stress in soybean plants: soil dryness, physiological dryness and atmosphere dryness. Drought events resulting from one of these conditions result in physiological reactions, depending on the developmental stage of the plant. For instance, during early developmental stages, a lack in su cient water supply could lead to decreased emergence or poor seedling growth. In later developmental stages however, drought was reported to lead to an abandoning of pods, stunt owering and pod set, poor seed lling and in further consequence to poor seed quality, sudden senescence and drop of *source*- leaves. Also, plant growth anomalies such as dwarf growth or deformation have been associated with osmotic stress. However, drought stress during pod-setting and - lling (especially during R4 stage) proved to have the most adverse e ects on yield, as the seed number- and size decrease (Liu et al. 2008).

In addition, if drought occurs during the vegetative developmental stage, it would lead to low leaf area index (LAI, see Chapter 3.1.2.12.6), decreased incoming light interception, as well as de cient maximum total biomass, which could not be fully compensated by irrigation in the subsequent developmental stages (De Costa and Shanmugathasan 2002).

Experiments also revealed that irrigation had positive e ects in all the developmental stages, whenever prior drought stress was experienced. Most bene cial additional water supply was observed during owering, which led to enhanced max number of pods initiated, improved Harvest Index (HI) and mean pod growth. If, additionally to the owering stage, the vegetative stage was exempted from drought, greater radiation interception during the pod- lling stage and more bene cial foliar development (enhanced LAI and consequently enhanced assimilates) were observed (De Costa and Shanmugathasan 2002).

Massive canopy development during the vegetative period on the other hand resulted in increased respiration rates, leading to negative e ects, if subsequent drought occurred. Therefore it seems crucial to maintain water supply during the owering period, if a larger canopy had developed prior to the stress event e.g. during vegetative stage, concluding that total biomass is an important indicator in determining yields (De Costa and Shanmugathasan 2002).

In summary, lack of water at any developmental stage caused yield reduction, but soybeans are able to compensate, depending strongly on the duration of water stress and the developmental stage in which water stress occurred, as well as on subsequent precipitation rates in following the developmental stages. Best overall results (including yield as well as Harvest Index and radiation interception) were achieved with su cient water supply during vegetative stage, followed by additional su cient water supply during owering period, with least improvements being observed with additional adequate water supply during pod lling period (De Costa and Shanmugathasan 2002).

Cultivars with higher water use e ciency proved to be more drought tolerable, due to their ability to maintain biomass accumulation throughout water stress events and furthermore continued allocating photosynthates to nodules, leading to continuous nitrogenase activity and hence maintaining nitrogen xation (BNF, see Chapter 3.1.2.9.1) (Purcell et al. 1997).

Furthermore, soybean genotypes treated with NH_4NO_3 proved to be more drought tolerant than genotypes relying solely on N_2 xation (Purcell et al. 1997). Liu et al. (2008) also stated that osmotic stress caused alterations in membrane lipids con guration, as well as enhanced permeability (see Chapter 3.1.3 on seed composition). For instance, soybean genotypes with improved drought tolerance showed increased content levels of phospholipids glycerol and increased concentrations of palmitic acid, whereas linoleic acid concentrations decreased. Similarly, altered fatty acid composition were observed as well as more oxygen free radicals, enhanced peroxidase activity and higher proline accumulation, especially in leaves (more than e.g. in stems and petioles) and especially (one-fold higher content levels of proline (see section below)) in more drought tolerant soybean cultivars compared to less drought tolerant cultivars. Concluding that there is a positive correlation between proline levels and drought tolerance in soybeans (see also Chapters 3.1.3 on seed composition).

Proline a compatible osmolyte and osmoprotectant and its effects on higher plants

Proline is a highly water soluble, non-essential alpha amino acid (Kavi Kishor et al. 2005 and Wiesler 2012, 279) a compatible osmolyte, which is not charged at neutral pH. Proline has shown little or no disturbing e ects on macromolecule-solvent interactions even at high concentrations. This suggests proline to have a role as osmotic balance agent, being capable of protecting subcellular structures. An accumulation of compatible solutes such as proline subsequently leads to enhanced cellular osmolarity, causing in ux of water or reducing e ux (Kavi Kishor et al. 2005).

An increase in proline concentration was rst observed in wilting perennial ryegrass and was later discovered to be part of a common (physiological) response, found in a large variety of higher plants (Ábrahám et al. 2010 and Shao et al. 2009), if they are exposed to a range of environmental abiotic stresses, such as high salinity, drought, chilling, heavy metals, hypoxia, water stress, UV irradiation or pathogen infection (Ábrahám et al. 2010 and Di Martino et al. 2006).

Although physiological responses during abiotic stresses such as water stress or salt stress lead to cellular proline accumulation in cytosol in certain higher plants (Kavi Kishor et al. 2005 and Shao et al. 2009), it is still not clear whether this process is a mechanism in order to endure drought more e ectively, or if it is a stress induced metabolic reaction (Di Martino et al. 2006).

If proline gets accumulated, it exceeds the normal level up to a hundred times, which accounts for a few millimolar concentrations, depending on the intensity of stress and plant species. An increased biosynthesis of proline is not only caused by the activation, but also a decreased or even inactivated degradation induced e.g. by osmotic stress. These mechanisms lead to an enhanced proline accumulation up to 80% of the total amino acids present during abiotic stress, as well as to decreased levels about 5% proline content in rehydrated plants (Kavi Kishor et al. 2005 and Shao et al. 2009).

With a plant experiencing water de cit, the maximum proline accumulation level is stated to occur at owering stage, while the lowest accumulation level was found to occur at vegetative stage (Shao et al. 2009). Despite of reported improvements in osmotic tolerance while experiencing water stress, the speci c role of proline throughout plant growth remains mostly unclear (Kavi Kishor et al. 2005).

For instance, it was suggested that this particular amino acid could act as a major compatible osmolyte and osmoprotective compound in osmotic adjustment, which e ectively increases the osmotic status of the plant by acting as a molecular chaperone (Ábrahám et al. 2010 and Shao et al. 2009). Consequently with proline being involved in processes of the osmoregulation and osmotolerance, overproduction could result in higher tolerance towards osmotic stress (Di Martino et al. 2006). Moreover, during water stress L-proline seems to have diverse roles such as to protect cellular and sub-cellular structures, as well as stabilising membranes and protein structures (Ábrahám et al. 2010 Kavi Kishor et al. 2005 and Shao et al. 2009) and preventing aggregation during refolding (Ábrahám et al. 2010 and Bach and Takagi 2013).

Thus proline helps reduce photodamage in the thylakoid membranes and protects cellular functions either by reducing the production and/or scavenging of O_2, for it is capable of acting as a free radical (reactive oxygen species -ROS) scavenger (Ábrahám et al. 2010; Di Martino et al. 2006; Kavi Kishor et al. 2005 and Shao et al. 2009). Through this ability it is capable of reducing damages resulting from oxidative stress. This is one effect occuring during drought, chill, heat, high salinity, UV-irradiation or which mitigates the inhibition of di erent enzymes by heavy metals. Besides it may be more relevant in helping plants to endure stress rather than acting merely as an osmolyte (Ábrahám et al. 2010; Di Martino et al. 2006 and Shao et al. 2009). Proline furthermore seems to be able to stabilise redox potentials and $NAD(P)^+$/ NAD(P)H ratios, while enduring water stress (Ábrahám et al. 2010).

An increase of this particular alpha amino acid was further observed to occur simultaneously with antioxidant enzymes quite often as well as soluble sugars in a variety of genotypes of *Radix astragali* seedlings, by enhancing chilling stress in cucumber or drought stress in soybeans (Shao et al. 2009).

The enhanced level of proline synthesis and decrease of degradation during various abiotic stresses are also related to a decrease in leaf water potential. However, as mentioned before, the accumulation of proline seems to be a mere symptome of stress and not an adaptive response (Shao et al. 2009).

To summarise, despite various results con rming a positive e ect of proline accumulation within plant cells, this does not mean that proline accumulation should be considered to be an isolated and exclusive phenomenon for stress tolerance. Although results suggest that free proline levels may serve as indicator for physiological status and/or the stress level of higher plants (Ábrahám et al. 2010).

3.1.2.12.5 Root system in soybean breeding Nodules in which biological nitrogen xation (BNF) of atmospheric nitrogen takes place (also see Chapter 3.1.2.9.1 on BNF) are located at the lateral roots (Mechtler 2012 and Diepenbrock et al. 1999, 245). Root systems consequently also in uence the BNF estimates (Schipanski et al. 2010).

In soybean stands quickly developing roots are of speci c interest, to support growth in an early plant stage (see Chapter 3.1.2.8 on competitiveness against weeds), as they help in overcoming weed pressure in early developmental stages (Shao et al. 2009).

Research situated in soil sciences and crop sciences place increasing focus on something termed *root architecture* which describes the 3D plastic composition of the root system within the soil. Considering current predictions on future developments (e.g. climate change scenarios, enhanced extreme weather events like drought and scarcening nutrients such as phosphorus drought events) improvments in correlated traits (like improved drought tolerance or enhanced nutrient utilisation) are strongly linked to the root architecture (as well as the soil water content and will continue to be more thourouly adressed in the future (Jannik et al. 2001; Lynch et al. 2012, 343 and Shao et al. 2009).

An additional concept related to aspects with drought tolerance and root systems is *termed ecohydrology.* It is currently gaining in attention and aims at using enhanced *green-water*, which is water taken up and stored by plants in the rootzones, rather than focussing merely on *blue water* (Lal 2013). Furthermore issues related to osmotic stress are targeted through the introduction of symbiosis with arbuscular mycorrhizal (AM) fungal. These symbiosis enable symbiotic partners to exchange water and nutrients and are even reported to work between di erent plant species as long as they are connected through fungal hyphae. This is especially stressed as promising research subject in semiarid dryland farming systems (Zarea 2010, 197, 207).

Moreover crop species often show adaptions to disturbed soil systems (like agriculturally used soil), leading to a root system close to the soil surface. This indicates adaptions to longterm fertilizing practices (Lynch et al. 2012, 343), but additionally favours negative e ects like enhanced leaching and runo and even resulting in eutrophication of freshwater systems. For example, from a total amount of phosphorus applied 50-80% of P reportedly accumulated in the soil instead of being taken up. Studies conducted in Germany consequently suggested an annual P loss in agricultural systems between 50-200 kg P/km^2 (Zarea 2010, 215).

3.1.2.12.6 Light interception, leaf area index/-duration (LAI/LAD) Generally, leaf area index (LAI[25]) patterns start with a lag increase in the beginning of the growing period, which is subsequented by rapid growth until a maximum LAI-value is achieved. After $LAI_{max}$was reached, decline sets in, as senescence of the leaves ag the beginning of the ripening stage (Setiyono et al. 2008).

For instance in irrigated soybean stands without water stress (see Chapter 3.1.2.12.4 on osmoregulation) LAI_{max} was reported to be mostly achieved at the end of owering stage (55-57 DAS), whereas maximum biomass accumulation was usually achieved during the pod- lling stage (70 DAS) (De Costa and Shanmugathasan 2002).

Improved LAI therefore leads to bene cial e ects on seed yields and might be achieved by a) increasing the plant population, b) enhancing fertilizer application, or c) improved water supply (Liu et al. 2008). Optimum LAI values however are thought to be quite divers and cultivar-speci c, depending largely on plant characteristics such as leaf-shape, canopy architecture and leaf-development. In a Chinese region, yields of 3 250- 3 600 kg per hectare were only achieved with LAI_{max} values exceeding 4 during a period of 30 days after owering. Bene cial e ects on seed yields on the other hand were also reported in connection with slowed senescence after R5 stage. According to Chang (1981, as cited in Liu et al. 2008) an ideal LAI with which 3 000 kg per hectare were achieved near Songhua river (China) would be 3 4 at R2, 5 6 at R4, 4.5 5 at R5 and 3 4 at R6.5. However these LAI patterns demonstrate how the photosynthetic rates of plants are closely related to plant leaf area and their developmental stages. Another example would be the photosynthetic capacity of soybean, which peaks at owering or early pod- lling stage, with young, fully radiated leaves, but starts declining thereafter (Liu et al. 2008).

Suboptimal LAI values or a decline of LAI with simultaneous absence of senescence of leaves might be the result of either mutual shading (with too large leaves which hinder

[25]The leaf area index (LAI) expresses the complete canopy density of a crop stand, which is capable of performing photosynthesis, and is measured per unit area of soil (Diepenbrock et al. 1999, 146, 39; Duveiller et al. 2011, 887; Heyland 1996, 168 and Liu et al. 2008). Hence, LAI characterises the structural properties of a plant stand in reference to its location characteristics and developmental stage (Jarmer et al. 2003) and is therefore a valid indicator of the vitality and productivity of a crop stand (Jarmer et al. 2003 and Liu et al. 2008). Consequently, LAI values develop throughout the growing season, as the relationship between photosynthetically active tissue unit and unit soil area alters (Diepenbrock et al. 2009, 146; Duveiller et al. 2011, 887 and Heyland 1996, 186).

In soybean stands, LAI values have been found to develop earlier maximum LAI when planted in high population densities. A maximum LAI of 4.5-5 at flowering period (as found by Guo et al., 1964, as cited in Liu et al. 2008) for instance would indicate that a unit leaf area would shade the corresponding unit area of soil 4.5 to 5 times (Diepenbrock et al. 2009, 146 and Heyland 1996, 187f.).

light transmission of getting into the canopy, or leaves in upper plant heights, which shade leaves that sit a little lower in the canopy architecture and thus reducing photosynthetic activity), or water stress (Liu et al. 2008 and Rotzler et al. 2009). However both scenarios (mutual shading and water stress) will result in yield loss. If shading occurs (notably in high-density canopy) during reproductive phases, it reportedly reduced seed- and pod numbers and could potentially also be responsible for considerable yield loss (Liu et al. 2008 and Jin et al. 2010), mainly due to diminished light, resulting in a lack of ux in su cient assimilates inside a canopy as well as in sinks (e.g. owers and pods) (Jin et al. 2010).

Enhanced light interception rates at late vegetative or early owering stage (and even at pod lling stage) on the other hand could increase yield levels tremendously (Liu et al. 2008). This points out the severity of light interception as major in uence factor in respect to yield (Liu et al. 2008 and Jin et al. 2010) and furthermore indicates that lowered LAI with simultaneous high leaf photosynthetic rate would allow higher planting densities with delayed decrease in photosynthetic rate due to mutual shading (Jin et al. 2010).

Ultimately though, this implies that e orts in breeding, selection and genetic improvements for high-yielding cultivars were inseparably linked with a selection for greater leaf photosynthetic rate (Jin et al. 2010), which is emphasised by the fact that soybean genotypes vary in their photosynthetic rate (Jin et al. 2010), with high-yielding genotypes generally having higher photosynthetic rates compared to non-high-yielding genotypes (Liu et al. 2008).

Again, these results indicate a positive correlation between photosynthetic activity and yield, with greatest impact reported to occur during seed lling stage (Liu et al. 2008 and Jin et al. 2010).

Especially during drought stress, improved seed biomass is stated to be achieved by enhanced translocation of (most readily available) assimilates and stored primarily in vegetative organs (De Costa and Shanmugathasan 2002). Higher yields were also associated with a more rapid closing canopy (and therefore faster increasing LAI), as well as higher interception rates of higher radiation levels due to elevated temperatures early in the season (Cooper 2003).

In addition, radiation interception (and conversion) also a ected total biomass production (De Costa and Shanmugathasan 2002), whereas solar radiation intensity was reported to be negatively correlated to seed weight (Li et al. 2014), Moreover massive plant canopy leads to moist and little aered microclimates and might even lead to increased abandonment of sinks (i.e. pods or owers) as a result of too high energy input for biomass production (Rotzler et al. 2009 and Schori et al. 2003).

However, studies conducted in north-east China revealed no correlations between Harvest index (HI[26]) and seed yield, but rather showed major in uences of the maturity groups on LAI, LAD and dry matter accumulation (Liu et al. 2005).

Seemingly, traits such as rapid leaf formation and growth as well as delayed senescence point towards high yielding soybean genotypes in north-eastern Chinese regions. Hence it was recommended to place more attention on such characteristics, especially in early maturing genotypes (Liu et al. 2005).

In summary, seed yield is strongly in uenced by leaf area index (LAI, especially after R4 developmental stage), LAI_{max}, photosynthetic activity, leaf area duration (LAD, especially during R2 to R5) and dry matter/biomass accumulation during the reproductive stage (especially during R5 stage and seed yield) and genotype and maturity group (Liu et al. 2005 and Liu et al. 2008). Improved yield could therefore be associated with higher dry matter accumulation and improved solar energy use e ciency (Liu et al. 2008).

3.1.2.12.7 Foliar disposition As mentioned above, light transmission considerably in- uences leaf area index (LAI). Consequently, so do the spatial distributions of leaves, as well as the leaf orientation and inclination angles. As a result, improved canopy architecture may enhance net assimilation rates and subsequently yields (Liu et al. 2008).

Altered photosynthetic processes during owering and pod setting stage also in uence seed yield by being tightly involved with pod production and seed number (Jin et al. 2010).

Crop management decisions that in uence the light interception rate and the foliar disposition in a soybean stand to a considerable extent are choices concerning the row distance and the chosen plant density. Narrower row spacing for example supports higher net assimilation rates (Fritschi et al. 2007 and Liu et al. 2008), even though genotypic di erences in chlorophyll constitution cannot be neglected (Fritschi et al. 2007).

In addition (and only up to a certain degree), plants are capable of adapting the leaf anatomy and physiology to intercepted radiation conditions. Such adaptive responses include a thickening of leaves, which is achieved by enhancing the mesophyll to surface-area ratio and thus reducing total chlorophyll content either per unit leaf area, or through enhancing the chlorophyll a/b ratio[27] (Fritschi et al. 2007).

[26] Harvest Index is established e.g. by initiated pod number and seed biomass increase (De Costa and Shanmugathasan 2002).

[27] The chlorophyll *a/b* ratio has been suggested to serve as a reference in order to establish radiation

For example soybean genotypes with large foliage tend to create a microclimate that is susceptible to diseases like *Sclerotinia* (see Chapter 3.1.2.11 on diseases), which is precicely why breeding e orts in Switzerland aimed at a reduction in leaf area over the past 10 years. Success was particularly achieved by crossings with lancetolate-shaped leaf-types, ultimately allowing for an additional reduction of the leaf area over 15% (Schori et al. 2005, 44).

Another example from China aims at soybean foliage, which should be uniformly orientated in a horizontal way, because lower inclination angles would allow for improved light interception and light penetration into canopy. These changed inclination angles take e ect especially during yield formation, when the leaf inclination angle has great in uence on photosynthate supply and hence yield formation (Jin et al. 2010 and Liu et al. 2008).

Noteworthy may also be that late maturing soybean cultivars from this example in China were characterised by higher inclination angles of the leaves, higher canopy closure and greater LAI, ensuring greater solar radiation interception into canopy, whereas early maturing cultivars were characterised by lower LAI, shorter plant height, fewer nodes and smaller canopy (Liu et al. 2008).

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conditions throughout plant growth (Fritschi et al. 2007). This function is of great value because light regimes are generally highly influential on source-sink-relationships (Liu et al. 2008).

Further, chlorophyll content varies significantly according to the position of the leaf on the plant (for instance, the chlorophyll content would be different if the leaf would sit near the top of the canopy compared to a position at the side of the plant. Variation is also caused by shading or through differences in nitrogen supply. Hence N plays a considerable role in chlorophyll contents, as well as in the chlorophyll *a/b* ratio. Whereas genotypic influences of soybean on the chlorophyll *a/b* ratio seemed to be negligible (Fritschi et al. 2007).

Jin et al. (2010) on the other hand pointed out that cultivars with improved photosynthetic rate (which may be achieved by reduced leaf area, combined with enhanced sink demand) seem to have improved translocation mechanisms as well as photosynthetic storage capacities.

Similarly, growth rates of sinks are tightly correlated with (and restricted by) the supply of photosynthates provided by sources, but might as well be limited by capacity boundaries of sinks. In both cases, limitations caused either by sources or by sinks are strongly related to genotype/environment interactions and the ratio between source- and sink size (Liu et al. 2008).

Under natural light conditions though, reduction in leaves (sources) has greater negative impact on yield than reduction in pods (sinks), which is especially true for plant stands with increased plant density. Under enhanced light regimes however, sinks also serve as important yield-limiting factors in soybeans (Liu et al. 2008).

In addition, photosythesis requires a lot of N with a proportion of 75% of leaf N relocated to the chloroplast. Crops in high irradiant environments generally show a ratio between 1.0 :1.4 mol N in ribulose-1,5-biphosphate carboxylase/oxygenase (RuBPCO) vs. N content measured in the thylakoid. In contrast that ratio shifts to the benefit of thylakoid N, if crops are grown in low irradiation environments (Fritschi et al. 2007).

Therefore, photosynthesis and leaf N are also closely correlated, as are leaf N content and N fertilizing rate with chlorophyll content (Fritschi et al. 2007).

Further, considering the shape of leaves, Rotzler et al. (2009) stated that oval-shaped leaves showed more powerful seedling growth, whereas lanceolate shaped leaves o ered more positive impact with regards to of the light interception of the stand, as well as higher photosynthetic activity rates. In cooler climates during owering period, though, the oval shaped isolines proved to have lower insertion heights of the leaves and higher yield stability due to enhanced longevity of the pods and enhanced thousand seed weight.

In contrast, plants with lanceolate leaves and altered leaf architecture resulted in improved chilling tolerance, earlier ripening dates, as well as smaller but higher numbers of seeds and possibly improved competitive power against weeds (Rotzler et al. 2009). On the other hand, reduced leaf area would also decrease tolerance against caterpillars or hail damage (Schori et al. 2003). Therefore, foliar disposition and leaf shapes are brilliant examples of how breeding success in one area may come at the cost of another, and consequently illustrating yet another example for trade-o s.

3.1.2.12.8 Influence of photoperiod (daylength) and temperature It is well known that late soybean planting dates (see Chapter 3.1.2.1 on planting dates) and especially delayed owering are negatively correlated with yield (Cooper 2003 and Egli and Bruening 2007), but although a trend of earlier planting dates in Midwest US proved to be bene cial (De Bruin and Pedersen 2008), the range of yield additions would strongly rely on location and year interactions (Cooper 2003 and De Bruin and Pedersen 2008).

Soybeans are a short-day plants, but daylength in Austria may reach 16-17 hours during the summer. Due to e orts in breeding, adequatly adapted varieties are now available that ower even under Austrian conditions and which also have good yield results (Brandstetter et al. 1993, 2).

Generally breeding e orts favour early ripening genotypes (Schuster et al. 2000), even though it was suggested that more emphasis should be placed on enhancing productivity per vegetation day (Schori et al. 2003), with respect to maturity groups, Liu et al (2005) stated late maturity groups to be more stable in yields and less susceptible to changes in the environment than early and medium maturing genotypes in the study region in northeast China (Liu et al. 2005).

In contrast, enhanced yields have been associated with high early spring temperatures (at sowing date), which trigger earlier owering and thus suggest a positive correlation between temperature and photoperiod (Cooper 2003). However studies suggest stronger sensitivity of oral induction (V0-R0) towards photoperiod than temperature (Cooper 2003 and Setiyono et al. 2007), while post-induction owering (R0-R1, within a threefold owering concept used by the authors) and maximum node appearance are more likely to be determined exclusively by temperature (Setiyono et al. 2007), concluding that sensitivity towards photoperiod and temperature are subject to seperate genetic regulation mechanisms (Cooper 2003). For instance, 6 genes or more have an additive e ect on soybean adaption to lower accumulated positive temperatures (Schori et al. 2005, 43).

Maximum radiation levels during the oral induction period (R0-R1), pod set (R1-R5) and post- owering (R1-R7) have also been found to signi cantly be correlated with maturity groups (Setiyono et al. 2007).

For this reason, too, top priority breeding e orts concerning imported plant breeding material (originating from places with diverging radiation levels) should improve the adjustment to altered radiation levels (Schori et al. 2005, 43). Interestingely though, further research also revealed that late owering isolines owered earlier when confronted with cooler temperatures. Breeding for early owering under cooler temperature conditions should therefore be possible (Cooper 2003). Furthermore it is already possible to achieve early maturing varieties by using late maturity parential lines in crosses, due to frequently achieved transgression (Schori et al. 2005, 43).

Although e orts should also be placed on shifting the initiation of the reproductive period earlier in the season, where radiation is more intense but without shifting maturity time (thereby stretching reproductive period and enhancing yield potential). As results showed a delayed owering barrier in areas with higher latitudes, which seemingly originates in increased radiation intensity due to sun angle as well as increased day length early in the growing season (Cooper 2003).

Current research hence attempts to create and optimise simulation models, which should help predict e.g. the period of time between sowing date and owering, or all plant level appearences of certain cultivars (Cooper 2003 and Setiyono et al. 2007).

3.1.2.12.9 Colour/degree of plant hair Soybean genotypes with severe hairiness on the bottom sides of the leaves showed reduced water loss and consequently enhanced tolerability against drought (Haberlandt 1878, 96f. and Liu et al. 2008). Genetically, the gene associated with photoperiod sensitivity, *E7* (Rosenzweig et al. 2008), is known to in uence the characterics of soybean hair. Also, gray haired cultivars often have an allele responsible for late maturing (E1) (Schori et al. 2003) accompanied by bright seed colours, which are strongly favoured by food processing industries (Schori et al. 2005, 44).

Alleles known to control early maturing on the other hand function in an additive way and are themselves recessive (Schori et al. 2003).

Furthermore, the correlation between brown plant hair, asynchrone owering and high seed yields would explain the widespread distribution of this genotype in European latitudes (Schori et al. 2003 and Schori et al. 2005, 44), leading to the conclusion that European plant breeders would have to close the gap between climatically better adapted soybean genotypes with brown plant hair and genotypes with grey plant hair and bright seeds, favoured by food industries (Schori et al. 2005, 44).

Besides, increased plant hair was also mentioned in connection with improved biotic stress resistance due to positive e ects of altering length and density of glandular hairs (pod trichoma) (Jin et al. 2010).

3.1.2.12.10 Lodging resistance, plant height, first pod height and shattering resistance If soybean plants are lodging (see Figure 22), this basically describes a lack of plant stability. Plant stability in turn is required to guarantee a maximum loss-free harvest (Schuster et al. 2000), because the harvester aims at cutting as close to soil surface as possible (see Chapter 3.1.2.10 on harvesting), which requires not only fully ripened seeds, but also soybean stands with high plant stability.

A precondition for plant stability is a healthy soybean stand. Decreased lodging is hence associated with reduced plant height, improved ripening and enhanced resistance to seed diseases and pest infestations (by reduced contact between plants and soil surface, which in turn serves as source of diseases), as well as with enhanced seed quality (not seed quantity, though) (Brady and Weil 1999, 492 and Jin et al. 2010).

Concerning biotic stress, which is matched with lodging scores, Jin et al. (2010) state that there might be various integrated or endo-processes working at a whole-plant level, such as altering ber concentration, or nutrients absorption.

Furthermore, plant stability is also related to plant height (Mechtler 2012), a trait mainly determined by genetic constitution (Soldati 1999, 673) and therefore growth types of cultivars, as described in Chapter 2.1.1 (on the botanical discription). Furthermore plant height is positively correlated with enhanced daylength (and subsequently connected to longitude), as well as accumulated growing period temperature, which is generally consulted in order to predict plant height. But plant height is also stated to be positively correlated with soil N and plowing depth (Li et al. 2014).

Hence plant height is also (but not primarily) in uenced by environmental conditions (Jin et al. 2010). For instance, water stress or cool temperatures during sensitive developmental stages of soybeans (e.g. cool temperatures 15 days prior to blooming)

Figure 22: Lodging soybean field

The photograph was taken on an experimental site of *the Chamber of Agriculture Upper Austria, in Upper Austria in* 2014.

lead to a reduction in plant height (Liu et al. 2008).

In contrast to plant height, lodging resistance is predominantly determined by environmental factors rather than by genetic disposition (Soldati 1999, 673), For instance, massive vegetative growth could indicate oversupply of N, leading even up to signs of accumulated nitrate (Brady and Weil 1999, 492).

Cooper (2003) also refers to the existence of a *lodging barrier* (Cooper 2003), which correlates lodging with very high yield levels (possibly in combination with unfavourable environmental conditions e.g. lack of water). For instance, extraordinarily high yields of 6 000 kg per hectare or more combined with lack of water or rainstorm would lead to severe lodging. Cooper suggests an implementation of semidwarf cultivars as well as shorter indeterminate cultivars in order to reduce problems related to limited yields if they would be directly linked to a lodging barrier.

Besides lodging resistance, breeding goals include improved non-pod-shattering properties (Diepenbrock et al. 1999, 248f. and Schuster et al. 2000), in order to guarantee minimum loss during harvest (Soldati 1999, 673), as well as enhanced st pod-height (Schuster et al. 2000).

But previous breeding success has already improved pod shattering dramatically (and even su ciently). Fully mature pods combined with dry air conditions still lead to seed loss through pod shattering, though. But since further improvements in pod shattering would ultimately lead to elongated internodes, and hence increased lodging, further improvements of rst pod heights are not included in current breeding e orts, at least in Switzerland (Schori et al. 2003).

A very low rst pod height was observed by Haberlandt as well, who suggested to include the roots when harvesting or alternatively to harvest as near at soil surface as possible (Haberlandt 1878, 93). Haberlandt s rst suggestion would imply carrying o even more nutrients from the elds, whereas the second suggestion still holds true to this day. Even though Mechtler (2012) identi ed breeding ambitions in respect to rst pod height as not necessary any longer. Despite it is a plant characteristic that is often questioned from practitioners, currently, commercially used cultivars in Austria vary very little. Besides research in respect to pod distribution in China revealed that pod distribution on the plants showed a majority of the pods to be inserted in the upper part of the plants anyway, followed by a medium quantity in the middle parts of the plant and lowest quantity of pods at the bottom of the plants (Liu et al. 2005).

3.1.2.12.11 Disease resistance: Biotic stress resistance/tolerance During emergence or seedling stage, main damage is caused by phesant poult, pigeons, hares, deer or caterpillars (painted lady), In order to reduce damage caused by game animals, it was suggested to use distracting animal feeding like soaked corn or wheat. Alternatively, offering perches for birds of prey, using scarecrows or choosing later sowing dates were also recommended (Brandstetter et al. 1993, 6).

Besides a general focus exists towards selecting for increased resistance against biotic and abiotic stresses (Schuster et al. 2000).

3.1.3 Seed composition, nutritional value, processing of products and current utilisation in Austria

Humans and animals have to rely on the more or less scarcly found, yet nutritionally important, proteins (Brady and Weil 1999, 491). Due to their high share in protein content soybeans are consequently of great value (with detailed information on the composition of its amino acids see Table 15). The dry seed mass for example has a characteristical mean value of 40% protein as well as a 20% fat/oil content (Ahmed 2002, 1; Diepenbrock et al. 1999, 245; Kumar et al. 2010, 375 and Soldati 1999, 672) which allows for a range of possibilities on how to use soybeans (summarised in Figure 23).

However in Austria soybean is probably best known and appreciated as source of high quality protein (Soldati 1999, 672), with a reported protein content ranging between 30-48% under Austrian growing conditions (Vollmann et al. 2008, 314).

Compared to other leguminous species (aside from *Lupinus* species, see Table 14) (Kumar et al. 2010, 375) this is an exceptionally high protein content. Although in most parts of the world soybean is most popular for its relatively high seed oil content (see Table 14, see also Chapter 3.1.4 on processing) which is used for oil extraction (Diepenbrock et al. 1999, 245; Kumar et al. 2010, 375f. and Soldati 1999, 663). On a global scale soybean-oil constitutes the second largest amount in oil used and produced, ranging right behind palm oil (*Elaeis guineensis*). This importance has also developed as a consequence to the ascribed bene cial characteristics of soybean, including its lack of cholesterol as well as its high content of unsaturated fatty acids. Therefore, even though the oil fraction is considerably lower compared to e.g. *Helianthus annuus* or *Brassica* species, soybean is predominantly perceived as oil plant and lacks of reputation and popularity as highly bene cial protein plant on an international level (Diepenbrock et al. 1999, 245; Kumar et al. 2010, 375f. and Soldati 1999, 663).

Additionally co-products of seed oil extraction such as soybean press cake and extraction meal are crucial for animal feeding and consequently traded on a large scale (see Chapter 3.1.1.1 on international soybean production e.g. Table 2).

A comparison between soybean and e.g. eld bean or peas furthermore reveals an improved amino acid composition of soybean (Ahmed 2002, 1) (see also Chapter 3.1.4.1 on animal feeding), despite of course this is highly depending on the requirements of the animal species and how the animal feeding material is processed. Nevertheless it should be noted that soybean extraction meal is also used as protein additive in wheat and meat products in human consumption (Diepenbrock et al. 1999, 245 and Soldati 1999, 663).

Further details on seed composition and related breeding goals are given in the following, whereas aspects related to processing are discussed in Chapter 3.1.4 (on processing).

3.1.3.1 Seed composition After harvesting, the water content of soybean seeds ranges between 14-30% moisture, depending on the weather before the harvest and the cultivar used. Dry (storable) seeds contain between 5-9.4% of water, roughly 23.9% carbohydrates, up to 6.3 % crude bre and up to 6.4% ash (mineral nutrients) (Diepenbrock et al. 1999, 247).

The crude protein of soybean contains 18 di erent amino acids (10 essential, 8 non-essential). Almost 90% of the soybean seed storage proteins are globulins which are

Table 14: Seed composition of selected legumes

legumes	dry weight	per kg dry weight			
		crude ash	crude protein	crude fat	crude fibre
	g/kg	g	g	g	g
fava bean	880	39	298	16	90
grain pea	880	34	251	15	68
yellow lupin	880	49	438	54	167
blue lupin	880	38	349	55	159
white lupin	880	41	376	88	136
soybean	880	53	**404**	**201**	60

Source: Kolbe et al., 2002, as cited in Mechtler 2012.

salt-soluble, while albumins constitute 10% and are water-soluble (L Hocine and Boye 2007).

Compared to meat and milk, the share of lysine and methionine are a little lower in soybean, but the biological value of the protein composition is very high, as can be seen in Tables 15 and 16 (Soldati 1999, 663). Compared to the total seed protein content found in soybean, 65-80% belong to the so called 11S (glycinin) and 7S (β-conglycinin) globulin storage proteins. In contrast to the 7 S group, the 11S is usually high in methionine and cysteine. However both groups (11S and 7S) are controlled by di erent groups of genes which are thought to be important e.g. for handling allergenic compounds that are associated with 7S storage proteins (Imstande and Schmidt 1998 and Kumar et al. 2010, 377). Furthermore 11S (glycins) constitute a share of about 40% on the total seed protein content, while 7S (β-conglycins) form a share of about 30% (Imstande and Schmidt 1998).

The oil fraction on the other hand contains a variety of fatty acids which are listed in Table 17. Saturated fatty acids (palmitic acid and stearic acid) form up to 8-12% of the oil fraction (Schuster et al. 2000; Soldati 1999, 672 and Qiu and Chang 2010, 17 .).

The linoleic acid (omega-6 (n-6)) and linolenic acid (omega-3 (n-3)), are also termed *essential fatty acids*, because humans cannot synthesise these amino acids by themselves. A selection on speci c contents concerning the n-6:n-3 ratios of selected plant oils is given in Table 18. These essential fatty acids are characterised by double-bonds at 6 carbon and 3 carbon (away from the last carbon (omega)), resulting in the terms n-6 and n-3. (Kumar et al. 2010, 377), Other active substances found in soybean include lecithin, tocopherol, iso avonoids (= phyto-estrogens, see Soldati 1999, 672) and biopeptides (such as lunasin) which contain the Bowman-Birk factor (see Table 19) (Kumar et al.

Table 15: Content and composition of amino acids of crude protein (g/16g N) in seeds of selected legumes

Amino acid	*Glycine max*	*Phasoelus vulgaris*	*Pisum sativum*	*Vicia faba*
isoleacine	5.1	4.5	1,.2	16.2
leucine	7.9	7.9	6.7	6.7
valine	4.7	6.1	5.2	4.3
methionine	1.3	0.7	0.8	-
phenylalanine	5.5	5.5	4.5	3.9
threonine	4.0	4.2	3.7	3.5
tryptophane	1.2	1.2	0.9	-
lysine	6.3	8.0	7.2	6.3
histidine	2.7	4.8	2.4	2.4
arginine	6.8	6.1	9.3	7.9
cystine	1.3	0.7	0.8	-
glycine	4.1	3.4	4.2	3.8
aminocarpoic acid	4.6	6.2	4.4	3.8
tyrosine	2.6	2.6	2.2	3.2
alanine	4.5	2.7	4.5	1.7

Source: Geisler, 1983, as cited in Soldati 1999, 671.

Table 16: Content and composition of 3 essential amino acids in protein in selected (protein) crops. Additionally protein content of co-product after starch or oil extraction

amino acid	*Glycine max*	*Brassica napus*	*Lupinus*	*Pisum sativum*	*Vicia faba*	*Zea mays*	*Triticum ssp.*
lysine	6.3	5.5	4.5	7.2	6.3	3.1	2.9
methionine	1.4	2.1	0.6	1.0	0.8	2.1	1.6
cystine	1.6	2.2	1.2	1.4	1.2	2.9	2.0
(m+c)/l	48	79	40	33	32	132	124
Protein content of co-product (5, DM basis)	53%	40%	42%	49%	52%	34%	41%

Source: A selection of the Table as cited in (EIP et al. 2014a, 11).

Table 17: Composition of fatty acids in soybean

fatty acids	content in % as cited in Hager (1978, vol. 7b, 209)	content in % as cited in Nature-Analysis Certi cate from 28.08.03	content in % as cited in Kerschbaum (2001, 16)
palmitic acid	2-11	10.9	11.7
linoleic acid	49-51	53.9	55.2
palmitoleic acid	-	0.1	0.1
oleic acid	23-31	23.6	20
alpha-linoleic acid	2-11	6.4	6.2
stearic acid	2-7	3.6	3.9
arachidic acid	0.9-2.4	0.4	0.3
behenic acid	-	0.5	0.3
vaccenic acid	-	-	1.6
myristic acid	0.1-0.4	0.1	0.1

Source: Krist (2013, 754). For further comparison see also Qiu and Chang (2010, 17 .);Schuster et al. (2000); Kumar et al. (2010, 393). and Soldati (1999, 672).

Table 18: Linoleic acid and linolenic acid and the n-6:n-3 ratio in di erent vegetable oils

oilseed	C18:2 (n-6) in %	C18:3 (n-3) in %	n-6 : n-3	Reference as cited in Kumar et al. (2010, 378)
soybean	53	7-9	6-7	Rani et al. (2005)
peanut	32.5	-	n-6 only	Nagaraju and Belur (2008)
sunflower	65.2	0.3	n-6 only	Zedak et al. (2006)
safflower	81.4	0.4	n-6 only	Lee et al. (2004)
mustard	25.3	11.3	2.0	Chowdhury et al. (2007)
canola	18.8	6.2	3.0	Huang et al. (2008)
olive	8.7	1.0	8.7	Zedak et al. (2006)
palm	10.2	0.5	20	Zedak et al. (2006)
corn	48.7	0.8	60	Rodrigues and Gioielli (2003)

Source: Kumar et al. (2010, 378).

Table 19: Components and concentrations listed refer to regularly used soybean cultivars

Component	Concentration in soybean
lunasin (peptides)	0.1-1.4 % of the seed
Bowman- Birk (peptides)	About 20% of the total trypsin inhibitor activity
iso avones	0.3% of the seed
tocopherols (α, β, χ, δ-isomers) (=Vitamin E)	1.5 mg g^{-1}oil
lecithin	0.5-1.5% of the seed
saponins (Group A, Group B)	0.5-1.5% of the seed
sterols	0.02-0.08% of the seed
ra nosaccharides	6% of the seed

Souce: cf. Kumar et al. (2010, 380).

2010, 375). Tocopherol (vitamin E) for example is a valuable antioxidant which is found in elevated quanitites in soybean oil (Soldati 1999, 672). However, for food and feeding purposes, substances such as phosphatides, saponins, oligosaccharids, sterols, edable bres and the share of phospholipids are similarly important (Schuster et al. 2000 and Qiu and Chang 2010, 17 .).

Minerals and Vitamins: The ash-content of soybean is 5-6% with the biggest share being potassium (2.3%), followed by phosphorus (0.6%), magnesium (0.3%) and calcium (0.2%) and minor minerals such as zinc, iron (8 mg $100g^{-1}$on dry weight basis), silicon, manganese, copper, molybdenum, chromium, boron and lead. Furthermore the mean value of water soluble vitamins in 1 kg soybean extraction meal containes 3.25 mg thiamin (B_1), 3.11 mg ribo avins (B_2), 16.9 mg pantothenic acid (B_5) and 29.7 mg niacin (B_6) (Kumar et al. 2010, 378).

Phytosterols: During tocopherol extraction, which is part of the crude soybean oil processing, phytosterols are derived as co-products. Phytosterols include campesterols, stigmasterol and sitosterol. The latter are characterised by the same ring structure as found in animal cholesterol which di er only in one side chain. Moreover total sterols consist mainly of sitosterol, followed by campesterol and stigmasterol (Kumar et al. 2010, 386).

3.1.3.2 Breeding targets related to consumption patterns in Austria Besides water, oil and fat, some components of soybean are unwanted (e.g. antinutritional components) or even dangerous for human or animal organisms if they are not processed properly or consumed in too high amounts. Another important aspect concerns unwanted substances, as they reduce the value of taken up animal feeding material. Consequently there are various techniques to improve safety issues and uptake rates of soybeans and related products.

For example soybean is not only toasted[28], but also incorporated as feeding component in accordance to the speci c health requirements of animal stock or human health requirements. If e.g. full-fat soybean is used in feeding, certain seed compositions require surveillance, as saponins, lecithin, phytic acid and proteinase inhibitors (listed in more detail further down in the same section) may pose dangers to the animals (Ahmed 2002, 1).

In order to achieve a decrease in dangerous substances of content a variety of techniques are available. A considerable reduction in undesired components may for instance be achieved through enzymatic inactivation or processing even though this may ultimately increase additional costs. One aim is therefore to target a reduction of unbene cial seed composition through plant breeding as well as the development of genotypes which lack antinutritiative components (Kumar et al. 2010, 387).

As already pointed out in the Chapter on agronomy-related breeding targets breeding traits are genetically interlinked and thus an improvement in one trait may lead to an undesired e ect in another one. Moreover quality parameters aimed at in breeding e orts strongly depend on the speci c use and purpose of the soybean variety. For example bene cial traits in genotypes developed for animal feeding purposes may vary from suitable characteristics required for human consumption purposes. However even within the same core area of utilisation di erences may be detected. Milling companies for instance, which produce soybean akes for cereals, do not share the same list of quality requirements on soybean seeds as companies which produce soybean drinks. Similarly, companies that specialise on animal feeding have di erent requirements on poultry feeding than on feeding material intended for swine industries. Consequently traits such as full-fat genotypes yel-

[28]Toasting is a treatment of soybeans involving hot water steam (Österreichische Arbeitsgemeinschaft für integrierten Pflanzenschutz 2013, 2f. and Soldati 1999, 672), which is very important if the soybeans are intended for consumption (see e.g. Chapter 3.1.4.1). Through this treatment, trypsin inhibitors and hämagglutinins are destroyed, which would otherwise have negative effects in respect of the protein uptake and N-free extraction substances (Soldati 1999, 672). At the same time it improves the taste and the biological value of the proteins, because of the deactivation of the enzyme urease (Österreichische Arbeitsgemeinschaft für integrierten Pflanzenschutz 2013, 2f.).

low hilum and high protein content are relevant for di erent industries. Still some shared interests exist and include e orts in improving safety characters in soybean products such as reducing allergies, or improving the digestibility. Hence breeding targets related to food consumption patterns (of animals as well as of humans) are diverse, depending on the use, even though some communalities may be found.

3.1.3.2.1 Food-grade quality In order to make processing easier the food grade quality aims at large and uniformly shaped soybean seeds. For tofu or soydrink production, yellow hilum and consistency are also listed as food grade quality criterions (Soldati 1999, 673).

- Breeding for yellow hilium:

A phenomenon that was observed with some brown-haired cultivars as well as with cultivars with a so-called colourless-hilum was a tendency of the hilum colour to di use to the colour of the seed coat. The resulting marbleisation was often mistaken for a disease and was thus less appealing in its appearance. Swiss breeding programs consequently put a lot of e ort into developing genotypes with yellow seeds and hilums which also were improved in taste. Improved taste was correlated with a lack in taste often associated with grass. Currently these improvements in taste are thought to be correlated with the absence of lipoxygenase, as it is suggested that lipoxygenase enzymes develop the characteristical grass-like taste when oxidising fatty acids (Schori et al. 2003).

3.1.3.2.2 High and stable seed protein content

- Breeding for environmental e ects, high seed protein content and high methionine content:

Permanent attempts are made to improve the crude protein- and crude fat content of soybeans (Diepenbrock et al. 1999, 248f.; Liu et al. 2008; Singh G. and Shivakumar 2010, 38f. and Schuster et al. 2000) which are breeding goals that probably range right behind increasing seed yield. Of similar importance are e orts in enhancing the protein quality by improving e.g. methionine contents (Diepenbrock et al. 1999, 248f.; Schuster et al. 2000; Singh G. and Shivakumar 2010, 38f. and Soldati 1999, 673).

Environmentally a decrease in protein contents is usually linked to higher solar radiation intensity and elevated mean maximum temperatures. Moreover success in breeding e orts for enhanced protein concentrations generally go along with decreased oil content. Oil-and protein concentrations are therefore negatively correlated. (Chung et al. 2003; Egli and Bruening 2007; Simpson and Wilcox 1983; Rose 1968 and Vollmann et al. 2008, 314).

Increased soybean oil content on the other hand was correlated with elevated mean maximum temperature and solar radiation, but negatively correlated with temperature and precipitation. Lower oil content was thus reported in environments with insufficient potassium levels which also lead to reduced 100-seed weight (Li et al. 2014).

In respect of elevated protein content a variety of factors are involved including for example year-interactions, growing conditions/environment, genotype, or variation in nitrogen sources. An assessment on Chinese growing seasons between 1950-2000 stated for instance that elevated mean monthly air temperatures resulted in significantly enhanced seed protein contents (Li et al. 2014).

Similar observations (increasing crude protein contents) were made in connection with elevated soil organic matter contents (SOM), reduced soil thickness, reduced phosphorus content, insufficient potassium content in the soil, as well as correlated with beneficially distributed precipitation patterns (Li et al. 2014) and variations in genotypes (Mechtler 2012; Rose 1968 and Pistrich et al. 2014, 68). It was further noted that the crude protein level was gradually enhanced with decreasing longitude (daylength), although the authors specifically emphasised significant correlation with longitude and precipitation distribution patterns in China with the latter gradually enhancing from west to east (Li et al. 2014).

In addition increased thousand seed weight (seed size) was also reported to be correlated with higher protein content (Pistrich et al. 2014, 68) as would late ripening times, enhanced plant height and number of nodes (Simpson and Wilcox 1983).

This list illustrates that protein content is influenced by a great variety of aspects, not all of which are non-controversial. In contrast to some authors (e.g. Jin et al. 2010 and Li et al. 2014) who found no significant correlations with protein/oil content and year interactions, others (e.g. Dornbos and Mullen 1992; Pistrich et al. 2014, 68 and Vollmann et al. 2008, 314) reported for example that dry and warm weather during the seed filling stage would increase chances of high protein levels. In other words precipitation may have rather insignificant effects on crude oil/protein contents in general, but this changes when high precipitation rates occur during the seed filling stage. During this developmental stage heavy rain may consequently lead to drastical reductions in protein contents.

Furthermore high protein contents are often correlated with lower yields (Egli and Bruening 2007 and Vollmann et al. 2010) even though little is known about the exact interrelations and further research would be needed. It is clear however that the availability of su cient nitrogen during the pod- lling stage is crucial for the development of the protein content and by extension for the formation of seeds/yields.

Moreover Egli and Bruening (2007) evaluated the N uptake characteristics in soybean leaves, petioles and stems, in order to nd out about di erences between high protein and low protein producing genotypes. They found signi cant di erences in total seed N and the amount of yield at maturity between both groups. Egli and Bruening however could not establish su cient evidence to support the hypothesis of N concentration in seeds deriving from larger vegetative N reservoirs in one group. In contrast Imstande and Schmidt (1998) stated that during the pod- lling stage soybean remobilises vegetatively stored nitrogen and sulphur (S) to the seeds. This would also be the reason why the types of nitrogen sources ($KNO_3$3, urea or urea assimilated; see also Chapter 3.1.2.9 on N fertilizer use) would a ect grain legumes in their N- and S assimilation rate as well as their seed yield levels and their seed quality. They additionally stressed the need for further research, as a lot of questions with regard to relative rates of N and S remobilisation during the pod- lling period still remain unclear.

Seemingly though vegetative N in mg per mg plant organic S would be speci c to plant species and would be usually well balanced. For example in the case of temporary N de- ciencies S assimilation is limited or stored as inorganic sulphate in vacuoles. Temporary S de ciencies on the other hand result in limited N assimilation even though NO_3^- could be continuously accumulated (Imstande and Schmidt 1998).

However N-sources are also stated to a ect β-conglycinins concentrations, as this seed protein does not contain cysteine and methionine residues (see Chapter 3.1.3 on seed composition) which would ultimately alter the N/S ratio within the seeds and which would consequently lead to a decrease in the nutritional value. Such a reduction in the nutritive value of soybean seed protein would be achieved by reducing cysteine and methionine residues in storage proteins through a favouring of the synthesis of β-conglycinins. The breeding goal is therefore to increase methionine levels in order to enhance nutritive levels of soybean protein (Imstande and Schmidt 1998).

Moreover according to Imstande and Schmidt (1998) up to 62% of whole-plant N could be remobilised during the pod- lling period, but N_2 xation would ultimately alter the facilitation of N to seeds. This seems to illustrate how chemically reduced nitrogen of the xylem might be translocated rather into pods than being invested into vegetative growth. Phloem nitrogen on the other hand is directed to the pods and mainly transported as asparagine and glutamine rather than nitrate. In contrast during pod lling sulphur is transported mainly as sulphate in phloem, although small amounts of formylglutathione, methionine and cysteine may be transported as well. If sulphur would not be present in su cient amounts during pod- lling, β-conglycinins would be subsequently be favoured in the synthesis. Therefore nutritional value of the seeds depend on seed yield and relative rates of N/S remobilisation in the seeds.

Furthermore N de cits are generally related to enhanced oil content and reduced protein content as well as increased sugar content (Vollmann et al. 2008, 314). This is explained by a lack of N leading to a reduced number of carbon (C) chains available for combinations with sugar molecules, which would normally be needed in protein formation (Brady and Weil 1999, 492).

Moreover during seed lling period N originates either from NO_3^- uptake, from N_2 xation or from remobilisation of N from vegetative tissues or pod walls to the seeds. The exact shares vary according to the availability. For instance nitrate uptake accounts for the major share during vegetative stage (depending on soil properties and availability of NO_3^-) which is followed by increasing N xation, as NO_3^- declines. Consequently the N uptake in general drops during seed lling stage. During this time (seed lling stage) remobilisation of N occurs as protein due to senescence processes simultaneously exporting amino acids to the seeds (Egli and Bruening 2007).

In summary each developmental stage is marked by characteristical origins of nitrogen which covers the N demand of the plant. In case of longer vegetative periods, as would be the case for late maturing genotypes, would consequently result in larger vegetative N reservoirs at maturity compared to seed N (Egli and Bruening (2007)).

Furthermore negative correlations with seed protein content and seed yield result in higher energy costs for accumulating additional protein in the seeds. This is explained by higher requests in glucose per g for the protein synthesis compared to the amounts needed in complex carbohydrates. Nevertheless in the study of Egli and Bruening (2007) in most years high-protein generating genotypes had signi cantly higher yield compared to non-high protein genotypes. In addition most high-protein genotypes accumulated higher total seed N contents. Besides it was suggested that these results were correlated with higher N xation rates rather than, as could have been predicted, increased senescence or altered seed- lling duration (Egli and Bruening 2007, see also Imstande and Schmidt 1998).

Egli and Bruening (2007) further point out that a reduction in oil content due to protein increase also leads to a reduction in required amounts of energy, as more energy would be necessary to synthesise oil compared to protein formation. This further highlights the negative correlation between seed protein level and oil content above mentioned.

In respect of N uptake and relocation/ xation and photosynthesis, it seems as though the complexity of these interactions would lead to sometimes contradictory ndings, because results do not always state seed yield reduction. Egli and Bruening (2007) state however that large vegetative N reservoirs do not seem to be required for further high protein genotype breeding e orts.

Furthermore protein levels signi cantly decreased under water stress situations, but were accompanied by increased proline levels (see Chapter 3.1.2.12.4 on osmoregulation). Shao et al. (2009) related this phenomenon either to the hydrolysis of protein or the protein synthesis by oxidative stress. But in studies on sun ower leaf protein contents rather contrasting results have been reported (drop in leaf soluble proteins as well as higher protein levels originating in elevated drought tolerance). Therefore correlations with drought resistance and protein levels of soybean are suggested, but need to be studied in further detail.

3.1.3.2.3 Food safety characters Food safety issues include not only a reduction in the allergenic potential of soybeans, but also breeding e orts for lowering linolenic acid, trans fatty acid and to prevent and reduce heavy metal uptake[29].

- Breeding for decreased allergenic proteins

Soybean is a major crop providing vegetable derived protein and oil (L Hocine and Boye 2007). Soybean components are used in a vast number of di erent areas (see Chapter 3.1.4 on processing). But the leguminous plant is also included in *the big eight* (L Hocine and Boye 2007) exposing soybean and seven other crops/substances as being believed to be responsible for 90% of all food allergies (or rather hypersensitivities, in the sense of an abnormal immunological reaction) (L Hocine and Boye 2007).

A major problem of soy allergy originates in soybean s wide use in processed foods[30], turning soybean proteins into hidden allergens, and subsequently making it rather complicated to avoid them. This is less problematic for ingredients in processed foods that

[29]Heavy metal uptake of soybeans is of great interest and a vast research area by itself. Therefore it would have exceeded the framework of this thesis and is not discussed in further detail.

[30]The vast diversity of how and where soybean is used, is depicted in Figure 23. Hence, soybean is not only found in processed food products, but also contained in cosmeceutical products such as hair care products, skin care products, sun care products, pharmaceutical e.g. medicinal gel capsules, antioxidants, medicinal agents, women's health products and industrial applications such as all-purpose lubricants, building products, cleaning products, plastics, textiles, soy biodisel,... just to name a selection (L'Hocine and Boye 2007).

are listed on the ingredients panel, but especially true if one of those listed ingredients itself would be enriched with substances deriving from soybean. Because this enriched soy compound within one of the listed ingredients would not show up on the ingredients panel of the product, but would still be potentially allergenic (L Hocine and Boye 2007).

Laboratories have documented immune system responses, but stated them to be towards many di erent fractions of soybean proteins, making it di cult to single out most consistent antigenics. Hence today 16 allergenic proteins have been identi ed to be responsible of a certain mechanism causing allergies. Progress is being made, but further research is necessary, because scientists are still not entirely certain about which soybean proteins precisely cause allergies. Most allergenic reactions intervene in metabolic-, storage- or protective functions, as many food allergens do. Further they are known for their features in relation with biological activities (L Hocine and Boye 2007).

The list of allergy causing soybean proteins, which have been identi ed so far, include a storage glycoprotein in vacuols (*Gly m Bd 30 K,* also known as P34) of the seeds (classifying it as a seed storage protein), which is said to be responsible for 65% of allergic responses. Another one was identi ed to be a hull hydrophobic protein (*Gly m 1*). But the authors also point out β-conglycinin, glycinin (as part of the 11 S fraction of soybean protein) to be potentially allergenic (see Chapter 3.1.3 on seed composition). Other hull hydrophobic lipid transfer proteins are *Gly m 1.0101, Gly m 1.0102* and *Gly m 2,* which are all linked to epidemic asthma and are classi ed as aeroallergens. In the list of soybean allergenic proteins is also Pro lin (*Gly m 3*), which showed analogies to a birch pollen allergen, as did soybean protein SAM22 (*Gly m4*), which is also tightly linked to birch pollen allergies (L Hocine and Boye 2007).

Other soybean proteins that have been associated with allergies or have been identi ed to be allergenic are P22-25, 50kDa, lipoxidase and soybean lecithin. During the past 20 years more enzymes, allergenic proteins and storage proteins have been found in the soybean germplasm resulting in breeding targets and mechanisms to reduce allergenicity. Consequently genotypes are now bred which lack Kunitz trypsin inhibitor (see below) or other proteins which have been identi ed as being allergenic. Despite a lot of e orts (and partial successes so far) it seems to be very di cult to remove all allergenic substances which are known today. In soybean lecithin for instance, various proteins have been determined allergenic, as e.g. one belonging to the acidic subunit of glycinin, a methionine-rich protein belonging to the 2S albumin class and a Kunitz trypsin inhibitor. Hence continuous research is de nitely needed (L Hocine and Boye 2007).

- Breeding for Kunitz trypsin inhibitor (KTI) free soybean genotypes (see breeding for reduced proteinase inhibitors)

Commonly found protease inhibitors in soybean belong to the family of Bowman-Birk or Kunitz. In chemical terms, Kunitz proteinase inhibitors have an inhibatory center for trypsin, while Bowman-Birk inhibitors are characterised through their molecular weight and their cysteine content. In addition Bowman-Birk inhibitors are more stable when treated with heat or acid than Kunitz trypsin inhibitors (Ahmed 2002, 14).

Kunitz trypsin inhibitor (KTI) makes up for 80% of the trypsin hindering activity, such as the inhibition of certain proteases including thiol, serine or aspartic protease. Due to these abilities KTI belongs to a group of proteins which are responsible for plant defence mechanisms (Kumar et al. 2010, 389f. and L Hocine and Boye 2007). KTI constitutes about 25% of soybean proteins and was found to inhibit growth, to cause pancreatic hypertrophy and hyperplasia in animals (Kumar et al. 2010, 389f. and Wang et al. 2012) and to cause hypersensitive reactions after ingesting or inhaling soybean products or extraction meal and hull as has been reported on humans. Kunitz trypsin inhibitor (KTI; 21kDa) was further connected to respiratory disorders in humans who were regularly exposed to soybean extraction meal and revealed KTI to be an occupational inhalant allergen (L Hocine and Boye 2007). Therefore trypsin inhibitors are important to be considered in animal feeding (see Chapter 3.1.4.1 on animal feeding).

Since KTI is heat labile a treatment with high temperatures helps to inactivate most of KTI, but some antinutrient activities remain, depending on the conditions of the treatment. Moreover this procedure influences the solubility of the soybean proteins and adds (considerable) costs. Consequently breeding efforts are made to develop KTI-free genotypes. The lack of a Kunitz trypsin inhibitor protein is passed on as a recessive allele to Tia, Tib and Tic and is also called null allele. Current efforts aim for an introgression of this null allele into high-yielding varieties. Hitherto existing successes include the KTI-free varieties *Kunitz soybean*, *BRM 925* and *BRM 262* (Kumar et al. 2010, 390) and Josefine originating from Austria (BAES 2015). And the discovery of certain KTI-linked single sequence repeat (SSR) markers has even accelerated developments in that field (Kumar et al. 2010, 390).

- Breeding for improved isoflavones patterns (phytoestrogenic effect)

Isoflavones are flavonoid compounds that contain two benzyl rings (C6) and are linked by a 3-carbon chain (Kumar et al. 2010, 381). Furthermore isoflavones accumulate in the soybean seeds during plant development, but are also found in root tissues. In the latter they are involved in the initiation of nodulation genes of rhizobacteria. This process supports a successful inoculation (see Chapter 3.1.2.9.1 on infection processes), but also attracts zoospores of root-rot pathogens (e.g. *Phytophthora sojae*). After infection with pathogens soybean plants produce iso avonoid phytoalexins in order to stop pathogens growth. Hence iso avones are also of major interest in respect of plant health issues (Dhaubhadel et al. 2003 and Jin et al. 2010).

Depending on genotype, year interaction (Dhaubhadel et al. 2003 and Kumar et al. 2010, 381) and use/dosage of fertilizer (N- xation) and irrigation, soybean seeds contain 1 to3 mg g 1 iso avones. The four main forms of iso avones found in soybean include free aglycones, as β-glucosides, as malonyl and as acetylated derivatives of β-glucosides (Jin et al. 2010 and Kumar et al. 2010, 381).

- <u>Breeding for soybean with high oleic and low linolenic acid (in respect of trans fatty acids)</u>

Improving the composition of fatty acids is a breeding goal connected to health issues (Diepenbrock et al. 1999, 248f.; Schuster et al. 2000. Singh G. and Shivakumar 2010, 38f. and Soldati 1999, 673). Amongst other substances of the seed composition (see Chapter 3.1.3) soybean oil comprises about 23% oleic acid (18:1), about 53% linoleic acid (18:2) and about 7% of linolenic acid on average. The latter is also responsible for rather limited shelf life as it is 21.6 times as susceptible to oxidation as oleic acid. Consequently oleic acid is aimed to be high whereas linolenic acid would preferentially be low (Kumar et al. 2010, 393f.).

Therefore industries partly hydrogenate soybean oil to enhance shelf life through improved oxidation patterns. Unfortunately this process also creates trans fatty acids which pose serious health risks because of their diabetogenic and atherogenic properties. As reaction some countries demand labelling of trans fats in food. In order to make the process of partial hydrogenation dispensable soybean breeding should also aim at developing cultivars that are high in oleic acid and low in linolenic acid. So far success in breeding was announced after two mid-oleic sources (FA 22 and M 23) have been developed using mutation breeding, as well as N98-4445A, which was developed through hybridization and selection and three high-oleic Canadian lines G 94-1, G 94-19 and G 168 with 80% oleic acid. Currently germplasm screenings as well as molecular markers for rapid introgression of the properties as well as transgenic approaches are expected to help develop improved cultivars regarding these traits (Kumar et al. 2010, 393f.).

As for the low linolenic acid content, one line (A29) was reported to contain no more than 1% of linolenic acid, with the remaining oil comprising properties which are thought to be even superior compared to high oleic varieties (Kumar et al. 2010, 394f.).

3.1.3.2.4 Consumption quality characteristics

- Breeding for improved lecithin content:

Amongst other functions lecithin is involved in plant growth and N- xation and is particularly found in leguminous plants such as soybean or faba bean. De-fatted soybeans hold a lecithin content of 1-3% of all protein content depending on environmental conditions, plant species and genotype. The substance is located in leaves, roots and stem tissues where it may inhibit enzymes of bacteria and fungi and hence help protect the soybean plant from illnesses. Lecithin taken up with animal feeding also causes reduced nutrient uptake. Consequently a *deactivation* of lecithin is vital in animal feeding (Ahmed 2002, 6 .)

In addition lecithin was mentioned in connection with allergeneic responses (L Hocine and Boye 2007).

- Breeding for lectin (phytohemagglutinins) content

Legume lectins are (glyco-) proteins that build complexes with ligands (with sugar epitopes of cellular glycoconjugate) and are hence linked to cell-cell recognition. This interplay between sugar and protein is involved in many regulative processes, including the folding process of proteins, the intra and inter cellular transport mechanisms of glyconjugates, programmed cell death (apoptosis) and adhesion of cells (amongst others) (Rüdiger et al. 2007, 706 and Pérez-Geminéz et al. 2012).

In soybean breeding they are of particular interest, as they are responsible for the speci city of rhizobacteria choosing its host. Hence, lectins are involved in inoculation (see Chapter 3.1.2.9.1 on speci city of host-rhizobium interaction) processes (Rüdiger et al. 2007, 725), even though the precise role of lectin is not entirely clear yet (Pérez-Geminéz et al. 2012).

Agglutinin, a speci c soybean lectin, may also be responsible for forming clumps of erythrocytes in the human body. Lectins in general are known for their ability to decrease the number of natural killer cells or blood insulin levels as well as to increase the size of the pancreas and to alter the absorption rate of nonheme iron. Moist heat treatment is able to inactivate lectins, but in case of the N-acetyl D-galactose, which is present in foods treated with moist heat, will prevent success and keep lectins active. In order to enhance the nutritional value genotypes with low lectin content would therefore be favoured (Kumar et al. 2010, 392).

Generally though plant derived lectins are in most cases not harmful for humans with exceptions of the AB-toxins (RIP-II) such as Ricin and Lectin of garden bean (Rüdiger et al. 2007, 720).

- Breeding for enhanced methionine content

Sulphur containing amino acids such as methionine are present in considerably larger amounts in soybean than in other leguminous plants, which is of signi cance in animal feeding (see Chapter 3.1.4.1 on animal feeding) (Mechtler 2012).

- Breeding for reduced proteinase inhibitors (see breeding for Kunitz trypsin inhibitors)

When e.g.poultry digest animal feeding one chemical process which takes place is the hydrolysis of proteins. Enzymes responsible for this mechanism include pepsin/trypsin and chymotrypsin. Together they are referred to as *proteinase*. Hydrolysis is a process in which peptide bindings are broken down and converted back to amino acids again. However this process may be drastically reduced if substances called proteinase inhibitors bind on both enzymes trypsin and chymotrypsin and as result reduce hydrolysis, subsequently causing reduced live-mass weight, less protein reduction and an increased size of the pancreas. It would therefore be important to reduce proteinase inhibitors for animal feeding purposes (Ahmed 2002, 14).

- Breeding for improved saponin content

Saponins are triterpernoid combinations with either one (mono) or two (oligo) saccharide side chains and aglycons. Saponins also belong to the group of glycosides with high a nity towards cholesterol, as well as membranolytic and hemolytic e ects. This leads to an improved permeability of cells (Ahmed 2002, 4f. and Kumar et al. 2010, 386).

Soybean seeds contain up to 0.5% of saponins (according to Kumar et al. (2010, 386)) or up to 6,5 mg/g T (according to Ahmed (2002, 3)) depending on environmental conditions and processing procedures of the products (Kumar et al. 2010, 386). According to their share of aglycone, saponins are divided into two groups: a) acetylated saponins (in seed germs) and b) aglycone structured saponins, which are conjugated to DDMP (2,3-dihydro-2,5 dihydro-6-methyl 4H-pyran-4-one) and which are further evenly distributed throughout the embryo and cotyledons (Kumar et al. 2010, 386).

If saponins are fed especially to ruminant animal species, it would have negative e ects on the animals, including a steep drop of calcium, reduced crude protein digestibility and N-retention (observed in muttons). In experiments with rats, the iron-complex building saponins also reduced the iron incorporation in the liver which is supposed to be less in soybean than in lucerne (Ahmed 2002, 5f.).

- Breeding for enhanced tocopherol content

Soybean oil contains all four tocopherol isomers (α-, β-,γ- and δ-tocopherol) and is the richest origin of these antioxidative isomers. In general tocopherol is of major relevance in pharmaceutical use and was reported to be linked with a reduced risk of e.g. cancers, Alzheimer s disease and Parkinson (Kumar et al. 2010, 384).

- Breeding for low phytic acid (myo-inositol hexaphosphate)

In neutral pH-value, phytic acid is able to strongly bind to Ca, Mg, K and Na as well as to Fe, Cu, Zn and Mn, proteins and co-precipitates (Ahmed 2002, 9-13 and Deak and Johnson 2007). Through this process strong metal bonds (phytates) are formed. Sources of phytic acids include seeds of di erent wheats, legumes, nuts and oil plants, in which the concentration ranges between 1-5%. In roots, leaves, tubers and stems the concentrations are very low or even intraceable (Ahmed 2002, 9-13).

In soybean the concentration is said to range between 10 to 15 g/kg and during the generative stage phytic acid is predominantly found in the cotyledons. Physiological important functions include the store of phosphorus and in subsequent steps the storage of Ca, Mg and K (Ahmed 2002, 9-13).

Phytic acid is most problematic due to its characteristics of building complexes, in which nutrients are accumulated in case phytates can be hydrolysed by the phytase enzyme, leading to poor uptake of essential minerals and electrolytes (Ahmed 2002, 9-13 and Deak and Johnson 2007). This process on the other hand is strongly related to the pH-level and the Ca-concentration. To reduce the phytic acid concentration soybeans could be microwaved, leading to a decrease between 23 to 46%. Additionally soybean extraction meal contains less phytic acids in comparison to oilseed rape extraction meal. Furthermore enhanced nutrient availability was reported when phytase was added to the animal feed (Ahmed 2002, 9-13).

Antinutritional e ects of phytic acid derive from its binding properties with minerals like zinc, iron, manganese, calcium or copper. For hydrolysis the enzyme phytase would be required, which humans and animals lack, leading to the formation of phytic acid-metal complexes in the intestines, which cannot be absorbed but reduce the availability and hence the uptake of nutritionally important metals. Consequently animal feeding industries that rely primarily on soybean extraction meal need to add phytase enzyme or inorganic phosphorus, causing not only considerable costs, but the feces of monogastric animals receiving such processed feeding proved to contain higher accumulation rates of inorganic phosphorus and through fertilizing the elds with manure introducing them to the environment (e.g. agricultural soil and water) (Kumar et al. 2010, 391).

- Breeding for soybean with improved amino acid composition (sulfur containing)

Especially in poultry and swine animal husbandry soybean extraction meal does not cover the needs for sulphur-containing amino acids. Consequently these industries have to complement the animal feeding with synthetic methionine leading to higher costs. Therefore soybean cultivars with improved sulphur-containing amino acid contents would be favoured in animal husbandry/poultry and swine industries. As mentioned above (see Breeding for high seed protein content, high methionine content) this involves alterations of the ratios between the 11S (glycinin) and 7S (β-conglycinin) storage proteins (Kumar et al. 2010, 392).

- Breeding for decrese in lipoxygenase content (reduced *beany flavour*)

Outside south-eastern countries the *beany flavour* deriving from the lipoxygenase enzyme (iron-containing dioxygenase) in soybean seed is a rather undesired characteristic. Seed protein constitutes of 1-2% of lipoxygenase in three forms (Lox-I, Lox-II and Lox-III), which are divided into two classes, with varying optimal pH values (class I pH 9, class II pH 7). These speci c pH values are needed in order to form hydroperoxides which subsequently get hydrolised and form the aldehyde and ketone compounds. These aldehyde and ketone compounds in turn are the ultimate sources of this *beany flavour*. Lipoxygenase hence does not classify as an antinutritional factor. The activity of lipoxygenase is inhibited by iso avones, but the enzyme may also be inactivated by heat which again is connected to higher costs and also entails that proteins are transformed into an insoluble form (Kumar et al. 2010, 394).

- Breeding for soybean with reduced oligosaccharides (ra nose and stachyose) and improved plant soluble sugars

Oligosaccharides (ra nose and stachyose, or collectively summarised as ra nosaccharides or ra nose family oligo saccharides (RFOs)) are two galactose derivates of sucrose (sugars) responsible for atulence experienced after consumption of soybean (or soybean products) and are stable towards treatments with heat (Kumar et al. 2010, 390f.). According to Kumar et al. (2010, 387) though, recent research revealed bene cial e ects as well. Current research interest for example is placed upon possible prebiotic properties related to soybean oligosaccharides[31].

Oligosaccharids are classi ed as carbohydrates and in contrast to nucleic acids or proteins, oligosaccharids have a lot more options for appearing in certain variations while staying similar in size. In addition, the intramolecular exibility is lower, if compared e.g. with oligopeptides, leading to improved binding reactions of energetically favoured conformations and thus creating not very frequently found preconditions of passing on biological information. Thus highlighting rarely found characteristics (Rüdiger et al. 2007, 709).

In humans RFOs are only metabolised by micro ora in the lower intestinal tract resulting in the production of CO_2, hydrogen and methane. A reduction of RFOs may be achieved by extensive soaking, boiling, or through leaching. In animal husbandry (especially in poultry and swine industries) RFOs in uence the weight of the animals and decrease the energy uptake (originating from feed) of the animals. This results in energy loss and contribution to CO_2 release to the atmosphere due to atulence caused by animal nutrition. For animal feeding purposes RFO-free genotypes are hence looked for (Kumar et al. 2010, 390f.).

Although it should also be noted that soluble sugars in plants also play major roles in osmoregulation. Whenever plants experience stress due to lack of water (drought stress) the breakdown of polysaccharides leads to elevated sugar levels and in the following the ability to maintain turgor (see Chapter 3.1.2.12.4 on osmoregulation) (Shao et al. 2009).

3.1.4 Processing and utilisation

Soybean is truly multifunctional in its use. This characteristic is best illustrated in Figure 23. Soybean serves as important source for protein for both, human and animal consumption once processed (Setiyono et al. 2008).

In animal feeding it remains the major protein source due to its bene cial seed composition. For human consumption purposes it is also considered to be equivalent to meat, milk products, sh and eggs. Another bene t of soybean is it s suitability for people who

[31] Prebiotic characteristics related to soybean oligosaccharids are further discussed for instance in:

Bao Yang, K. Nagendra Prasad, Haihui Xie, Sen Lin and Yueming Jiang (2011): Structural characteristics of oligosaccharids from soy sauce lees and their potential prebiotic effects on lactic acid bacteria. Food Chemistry 126, 590-594.

Y. Lana, B.A. Williams, M.W.A. Verstegen, R. Patterson and S. Tamminga (2007): Soy oligosaccharides in vitro fermentation characteristics and its effect on caecal microorganisms of young broiler chickens. Animal Feed Science and Technology, 133, 286-297.

are lactose intolerant (Seifried 2014, 13; 22f.).

However consumption patterns are strongly related to the geographical region, local food patterns, as well as the cultural heritage (see Chapters 2.1.1 on the botanical discription and 3.1.4.2.1 on food as cultural heritage). Moreover consumption patterns also result in socio-economic impact on people and their environments. In our globalised world this also entails global responsibility especially towards anthropogenic impact on major soybean producing countries, where huge monocultures are established in order to cover the growing demands in global protein sources.

Nevertheless, increasing demand does not always need to be met by increasing supply, but should rather lead to critical assessments of our own consumption patterns (Seifried 2014, 94f.).

Currently enhanced demands lead to land-use e ects such as increasing deforestation of sensitive tropical savannas (mainly in South America, namely Brasil) (EIP et al. 2014a, 12) as well as to huge implications for locals. Furthermore extension in production acreage veils that fertile land abroad is exploited on our behalf (see Seifried (2014, 94f.)).

Another heated debate tightly connected to soybean consumption patterns are genetically modi ed (GM)-genotypes since leading soybean producers like USA or Brazil (see Chapter 3.1.1 on soybean production levels) use predominantly GM soybean varieties[32], as it s not di cult to handle and due to the application of a total herbicide (containing the active substance *Glyphosat*). Hence, most soybean imports (which originate mainly from the USA, Brasil and Argentina) at least contain GM-containing yield (Seifried 2014, 33f.).

In Austria the production of GM soybeans is prohibited (Austrian parliament, 1994, as cited in Pistrich et al. 2014, 99; 101 and Seifried 2014, 33f.). Accredited GM-feeding/or food stu within the EU needs to be declared starting with a content of 0.9% or more (according to the EU regulation (EG) 1829/2003). There is also a zero tolerance towards GM food or feeding that was not accredited for/by the EU (European Union, 2001; European Union, 2011) (Seifried 2014, 33f.). Due to rising criticism of consumers the demand for GM-free soybean is growing (Pistrich et al. 2014, 99 .; 13f.). However this tendency also causes bottlenecks for organic production systems with animal husbandry.

(EIP et al. 2014a, 12) welcomes this GM-free soybean trend because it would be a niche in a competitive market and hence would open up opportunities especially for human food industries. Negative aspects include global research being focused rather on GM-soybean

[32]Measured on the total soybean production volume in 2000 54% consisted of GM varieties (Fernandez-Cornejo et al., 2014, as cited in Seifried 2014, 33f.).

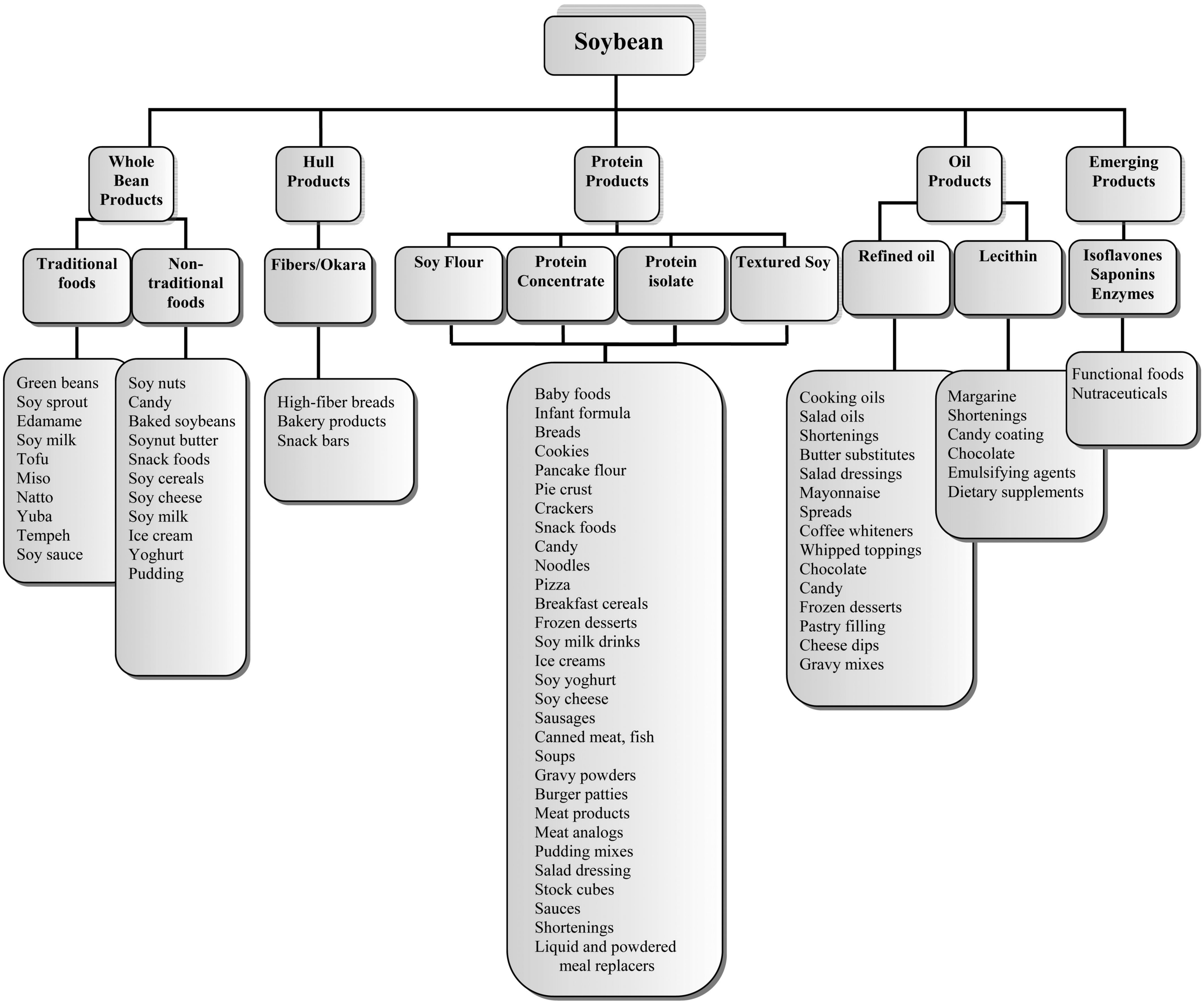

Figure 23: Di erent uses of soybeans as food

Source: L Hocine and Boye (2007). Note though that the term *soybean milk* is not to be used in EU countries anymore but needs to be substituted by *soybean drink*, since *milk* has been declared a protected term (Eggler 2010, 115 .).

and speci c GM-soybean-solutions (e.g. in respect of weed control) (Pistrich et al. 2014, 99 .; 13f.).

Besides the use of total herbicides would favour an increase of few tolerant weed species which would be characterised by being well adapted towards many characteristics of GM-soy use and would not be likely to increase the crop/weed diversity (Murphy and Lemerle 2006). Furthermore farmers would become more dependent on herbicide industries.

Another aspect related to consumption and processing patterns is the so-called protein gap. In Austria as well as in other EU countries there is a rather large gap between protein needed for animal feeding and protein sources produced in Europe. These lacking protein sources are covered by imports. The di erence between soybean demand and supply is called the protein gap (Pistrich et al. 2014).

The largest share of Austrian (non-GM) imports (see Chapter 3.1.1 on soybean production levels) comprises of soybean oil cake intended mainly for livestock industries. Although a reduction in import volumes was detected in recent years (from 9.9 m metric tonnes of oil cake imported in the year 2009/10). For example the volume was reduced to 9.3 m metric tonnes in 2012/13 (USDA, as cited in Toepfer 2013), a trend which is supported by the common European protein strategy which is currently in development. The main aim (also from EIP) is therefore to overcome the risks that go along with price volatility and dependencies on soybean imports (EIP et al. 2014a, 11). Consequently (EIP et al. 2014a, 12) highlights the breeding targets that aim towards closing the protein gap e.g. through enhanced yield stability, mixed cropping (grain legume/cereal) (see Chapters 3.1.2.4.1 on intercropping and 3.1.2.7 on crop-rotation and weed control), smart crop rotation, as well as improved water use e ciency - especially in the Mediterranean climate area (see Chapters 3.2 on the outlook; Chapter 3.1.4.2.2 on food security). EIP also highlighted the importance of interactions with soil, e ects of crops on soil health as well as on soil organisms (fungi and nematodes) (see Chapter 1.1.2 on soil health). The aims of EIP thus seem to be closely aligned with the concept of sustainability.

3.1.4.1 Soybean for animal feeding in Austria Generally, more than half of all Austrian soybean production is used in the food industries (human consumption). (Pistrich et al. 2014, 66f.; 92 and Seifried 2014, 22f.). However 80% of all soybeans grown or processed within the European Union (EU) are used for animal feeding purposes (Pistrich et al. 2014, 66f.; 92).

Moreover the total capacity of EU protein consumption used in animal feeding (including soybean) was estimated to be roughly 470 m tons per year. Almost half (230 m tons) of this total 470 m t per year is used for roughages grown on-farm. The remaining 240 m tons consist mostly of cereals (48%), oilseed extraction meals and cakes (28%) and other co-products deriving from the food industries (11%), amongst others (EIP et al. 2014b, 7 and EIP et al. 2014a, 11).

In Austria in the year 2014 27% of all needed animal feeding material was imported (VCÖ 2014, 34) which consisted on average of 570.000 tons of soybean extraction meal and an additional 100.000 m tons of whole soybeans each year (VCÖ 2014, 36).

Besides 70% of all protein-rich animal feeding materials used within the EU are dependent on imports (see also the key word *protein gap* mentioned in the Chapter above called 3.1.4 on processing; for further gures in relation of import volumes see also Chapter 3.1.1 on soybean production levels). With soybean consituting the (by far) largest share of more than 97% (EIP et al. 2014b, 7).

Notably feeding material strongly depends on the animal species and their speci c requirements as do the processing methods of the feed. Due to its bene cial seed composition (see Chapter 3.1.3) soybean (VCÖ 2014, 36), or more precisely soybean extraction meal, is used in huge amounts. Thus it is made the most important protein source in animal feeding (Kumar et al. 2010, 375f. and Pistrich et al. 2014, 66f.). Particularly swine industries, poultry and milk-cow industries rely on soybean extraction meal as feeding material (Kumar et al. 2010, 375f. and (VCÖ 2014, 36). Reasons for this popularity in poultry and swine industries are connected to the modes of digestion of monogastrids which - in contrast to ruminants - heavily rely on constant protein uptake. Ruminants on the other hand rely on pansen bacteria braking up amino acids (Pistrich et al. 2014, 66f.; Seifried 2014, 23f. and (Westhoek et al., 2011, as cited in EIP et al. 2014b, 7).

An aspect also illustrated by the data listed from van Gelder et al. (2008, as cited in EIP et al. 2014a, 7) who estimated soybean compound animal feeding within the EU to be distributed between di erent animal species as follows: 29% for pigs, 22% for layers, 37% broilers, 10% dairy cattle and 14% beef cattle (see also FEFAC and Bouxin 2013 and www.fefac.eu on the distribution of compound feed per year, distributed between animal species). This further lead to the calculated 232 g/kg beef and veal meat, 648 g/kg pork meat and 967 g/kg poultry meat, highlighting that poultry industries are most dependent on soybean compound feed. These variations are explained by EIP in relation to di erences between monogastrids and ruminants (EIP et al. 2014a, 7). With industrial compound feed output per livestock class in 2013 in the EU-28 being estimated by 42.35 Mt cattle, 49.2 Mt for swine industry, 51.4 Mt for poultry (FEFAC and Bouxin 2013).

The high signi cance of soybean in animal feeding dates back to the 1950s, where soybean oil cake and extraction meal was prepared with hot water steam thus inventing a processing of the oil crop termed *toasting*[33]). Through this treatment soybeans revealed to have even more ideal characteristics for animal feeding purposes, thus boosting its popularity.

Schori et al. (2003) refer to the Europarat when pointing out that after the prohibition of feeding bone meal and meat related products demands in protein-rich feeding materials enhanced as did requests of consumers pressing for higher traceability of livestock products, with particular focus on GM soybean imports used for animal feeding.

In addition organically farmed pig and poultry industries in Austria point out di culties rooted in insu cient supply with organic, GM-free soybeans for animal feeding purposes. Thus revealing a true bottleneck due to a lack in adequate amounts of organically produced soybeans available. Nonetheless organic animal husbandry is obliged (since 2012 according to the regulation VO (EG) Nr. 889/2008) to use organically farmed feeding materials whereas conventionally produced feeding material is completely prohibited (Pistrich et al. 2014, 68f.; 72; 75f. and Seifried 2014, 43f.).

This tensed situation is expected to further intensify in the year 2017, when treaty comes into e ect, allowing for a maximum value of merely 5% conventionally farmed additions in organic animal feeding materials (Europäisches Parlament und Europäischer Rat, 2009). These terms have been commissioned in a situation in which only 75% of the demand in organically farmed crude protein can be covered, despite acreage of organically farmed grain pea, vicia faba and soybean have almost doubled during the past 5 years (from 8.900 ha to 16.500 ha) (Seifried 2014, 43f.).

Alternative protein-rich crops used in the feeding industry include sun ower extraction cake, maize gluten or Dried Distillers Grains Solubels (DDGS), fava bean or grain pea. Still, soybean seems to be the most popular for reasons rooted both in its bene cial nutritional composition as well as in aspects related to pro t contributions (see Chapters 3.1.1.3 on economic aspects and 3.1.3 on seed composition) (Pistrich et al. 2014, 14; 66f.).

Compared to locally grown alternatives soybean proved to be superior in respect of e.g. it s nutritional value and more favourable compositions of amino acids (see table 20) (Pistrich et al. 2014, 14; 66f.). The latter originates in higher sulphur containing amino acid contents (methionine), high contents of lysine (with cysteine ratio to lysine being particularly important for the swine industry), less tannins, reduced trypsin inhibitor content or bitter constituents EIP et al. 2014a, 11 and Mechtler 2012).

[33]See footnote 28

Other reasons of preferring soybean over local alternatives like DDGS include challenges such as varying nutrient levels and elevated mycotoxin levels in DDGS. Further Dried Distillers Grains Solubels are only used to a limited degree in swine and poultry industries (Pistrich et al. 2014, 19). In livestock industries with ruminants rapeseed cake and colza extraction meal are also used. But these alternatives come with restrictions due to increased crude fat levels. Rapeseed use in swine industries is another example with rapeseed being only acceptable in limited amounts due to its glucosinolate contents amongst other quality aspects. In poultry rapeseed is barely used due to sinapic contents leading to a shy smell in eggs (Pistrich et al. 2014, 16).

Hence even though mixtures with alternative grain legumes would be possible in animal feeding e.g. a mixture of maize and peas (and probably in addition with sun ower hulls) which could be suitable e.g. for swine industries this mixture would still not be able to fully substitute soybean as feeding material (EIP et al. 2014a, 11). Thus highlighting once more the more or less unique status of soybean in animal feeding.

As established previously (see Chapter 3.1.3 on seed composition) it is most advisable to prepare soybeans with certain treatments before consuming them -which is true for humans as well as for animals). Otherwise (consumed in raw state) e.g. animals, especially monogastric animals like chicken or pigs, would have ultimate trouble e.g. due to the inhibition of trypsin (see Chapter 3.1.3.2 on consumption related breeding targets). This would further lead to hypertrophy of the pancreas and reduced uptake of the proteins (Schori et al. 2003).

Processing methods in order to inactivate trypsin inhibitors include heat treatments (Schori et al. 2003). Hence despite all positive characteristics of soybean, due to some undesired substances (see also in Chapter 3.1.3 on seed composition) and depending on the processing (mechanical, thermal, hydrothermal and pressurethermal treatment, or combinations[34]) there are restrictions and limitations in animal feeding which are rather speci c to the animal species in connection with certain seed compositions (Ahmed 2002, 21 and Kumar et al. 2010, 375).

Breeding targets aiming to upgrade animal feeding generally include improvements in oligosaccharid contents, amino-acids contents and improvements in the availability of nu-

[34]In the mechanical treatment, feed is being processed (milled, pressed, flocked) in order to create smaller peaces and pealed. This is often done in order to make thermal treatments of all kinds more efficient, as well as making feed easier to digest and prevent internal injuries (Ahmed 2002, 22f.).

Thermal treatments include hot air treatments, microwaving, roasting and infrared radiation (micronisation); hydrothermal treatment include autoclavation, cooking and the use of a hydroreactor; and pressure treatments include expansion and extrusion (Ahmed 2002, 22ff.).

trients while reducing costs and further avert connected phosphorus pollution (especially in poultry and swine industries) (Kumar et al. 2010, 375f., see also Chapter 3.1.3.2) on consumption related breeding targets.

Although the success of these treatments strongly depend on the time passing until the soybeans are processed as well as temperature, pressure and the moisture content of the soybeans (Ahmed 2002, 21). Furthermore it would be even more desirable and more cost efficient to be able to use whole seeds without additional treatments necessary- i.e. through improved genotypes (Schori et al. 2003).

Most commonly used variations of soybeans in animal feeding include soy 44 (including hull, 44% protein) and soy 48 (without hull, 48% protein) and fullfat soy (37% protein) (Seifried 2014, 25f.) with the latter currently forming a large focus in the feeding industries (Pistrich et al. 2014, 66f.). However in accordance to the animal species the shares of fat used in animal feeding are subject to regulations. This subsequently leads to restrictions and as a result acts limiting to animal feeding material with high fat contents (as e.g. in soy 44) (Pistrich et al. 2014, 69ff.).

Current research in the field is focussing e.g. on inventing methods for breaking up lignocellulose-complexes and to guarantee access to fiber-rich feeding materials in the future deriving from plant cells and being also rich in protein (by heat or pressing technologies, whilst eliminating toxic substances). Therefore research is keen on opening up new sources for protein-rich feeding material with an equivalent protein quality as found in soybean extraction meal (Mair et al. 2013). In combination with an aspired transition in diets alternative feeding materials are of great importance (see Chapter 3.1.4.2.2 on food security).

And even though grain legumes may be used directly on-farm (Mechtler 2012) the high fat content as well as the necessity to subject soybeans to certain treatments (e.g. toasting) in order to reduce undesired substances, on-farm use is somewhat problematic especially for self-utilisation on small scale farms (EIP et al. 2014a, 11).

3.1.4.2 Austrian (human) food consumption patterns

3.1.4.2.1 Food as cultural heritage and how soybean and meat consumption patterns in Austria are influenced by the cultural heritage About 150 years ago biochemistry and metabolic physiology evolved as new fields in research. This was accompanied by great enthusiasm, resulting in thorough research on food and food uptake. At the time the main focus was placed upon organic functions of food and their connections and

Table 20: Nutritional value of fodder of di erent legumes

legumes	dry weight	per kg dry weight										
		crude ash	crude protein	lysine	methionine	cysteine	crude fat	crude fibre	N-free extration matter	ME* pi	ME poultry	biolog. value
	g/kg	g	g	g	g	g	g	g	g	MJ (megajoule)	MJ	
fava bean	880	39	298	18.4	2.3	3.6	16	90	556	14.4	12.2	55-65
grain pea	880	34	251	16.7	2.3	3.4	15	68	621	15.5	12.8	50-65
yellow lupin	880	49	438	22.3	2.8	10.5	54	167	289	14.7	9.3	57
blue lupin	880	38	349	16.7	2.5	5.3	55	159	399	14.4	-	53
white lupin	880	41	376	19.9	3	5.3	88	136	359	15.5	-	-
soybean	880	53	404	25.9	6	6.1	201	60	282	17.6	15.3	86

Source: Kolbe et al., 2002, as cited in Mechtler 2012. *ME is a unit in order to compare convertible energy of large animals such as pigs or cows.

reactions to organisms. However this bundled attention strongly contributed in shaping further developments in the food-research sector. Consequently research was highly concentrating on (or reducing food to) nutritional and biological characteristics. It was not until a symposium held in May 1989 in Germany that this narrow attention was broken up by (re-)adding a cultural understanding to food (Lemke 2007, 169).

In her master s thesis Eggler (2010, 10) states that by preparing food, nourishment would be transferred from a natural- into a cultural state. Counter developments gradually evolved during the industrialisation. During this time a process set in which completely altered the consumer s perception of food. Consequently food consumption was completely detached from knowledge on it s origin. Advertisement suggested that the supply of these foods was (apparently) non-chained with on-site growing conditions (e.g. local weather), local cropping cycles or seasons (e.g. due to o -season crop cultivation). Food therefore became *degenerated*, with a cyclic notion of time and knowledge about seasonality of food being discouraged or even undermined by o ering *everything all year round.*

Additionally our taste is heavily in uenced by cultural and social aspects and long-term consumption patterns which evolved through hundreds of years, and are constantly handed down (e.g. through (family-) recipes). Consumption patterns would therefore be di cult to alter or adapt, even if e.g. environmental conditions would change (Eggler 2010, 11).

Food thus characterises people as it supports the formation of groups. Food and consumption patterns consequently send out massages, create social structures and even power-relations (Eggler 2010, 13 and 42).

It was not until the 20^{th} century when the soybean spread as a valuable plant for animal feeding purposes throughout the USA and Europe. At this point the soybean was rather neglected as human foodstu (Eggler 2010, 40). During war new sources of food needed to be found in order to secure su cient food supply for the population. At this point Haberlandt (see Chapter 2.1.1 on the botanical description) aimed at a food revolution. He thought soybeans in combination with potatoes to be ideal to serve as *staple foods* for *poor* people due to their favourable and supplementary combination of seed composition (Eggler 2010, 38 and 40f.).

Generally though in those days protein was predominantly consumed through meat, milk, butter and cheese in all Central European countries. Consequently products related to livestock, to this day, carry a speci c, historically evolved value. In this context meat was associated with power relations due to extended periods of times when mainly rich and powerful people were able to afford meat. Examining today's advertisements, they still tend to ennoble meat to an essential part of a meal, especially on Sundays or at certain holidays. Of course this impression of meat being a more luxurious good than e.g. vegetables very likely originates in higher production costs of livestock as well (Eggler 2010, 42-44).

In cookbooks published during the war (e.g. the *Wiener Soja-Küche* by Friedl Brillmayer and Henriette Cornides from 1945), the soybean always substituted other ingredients. Mostly because original components were not available at the time or too expensive during war times (Eggler 2010, 104f.). Besides during war soybean consumption patterns were deeply impacted by the NS regime while in post war period the same applied particularly for US food-aid (Marshall-Plan) (Eggler 2010, 56 ff.). However substitutions for various products were needed and found quite often in the use of soybean products. This is particularly interesting because soybeans were ever since intended to be incorporated in a way least noticable and not to stand out. Due to these circumstances soybean was never able to develop a reputation of distinctive qualities and flavours by itself or establish itself as a valuable food in the Austrian cuisine (Eggler 2010, 104f.).

Eggler (2010, 42 ff., 45f., 48) therefore points out that soybean, as a substitute of meat, clearly lacked in cultural value. Later meat (as well as milk) got cheaper and consequently more readily accessible and affordable for a larger public. Back then enhanced consumption of animal products represented progress and meat consumption increased followed once more by opposing trends (Eggler 2010, 48 ff., 103).

Simultaneously soybean for animal feeding purposes increased, too, with major import volumes deriving at first from China. After the Chinese Revolution in 1949 soybeans imported by Austria mainly originated from the US. Following the soybean shock from 1972 and US export prohibition of soybeans however, the USA were succeeded by Brazil and Argentine as major exporting countries. Additional effects resulting from these developments were introductions of vast monocultures, including the multitude of consequences that went along with them, in the main producing countries. The situation grew even more acute after EU's soybean imports were exempted from entrance duty and the introduction of restrictions on the EU legume cultivation (intended for animal feeding) through the Blair-House-treaty (Eggler 2010, 107 ff.).

In contrast protein sources originating from soybean in contemporary Austria appear to be profoundly influenced by lifestyle, gender, education and ideologies (Eggler 2010, 125 and 136).

The high (cultural) value of meat and meat consumption in Austria has consequently grown in the course of time. Accordingly the two sources of protein are assessed differently from a socioeconomical point of views, as meat is connoted with considerably higher (cultural) values compared to soybeans. Moreover these historically evolved connotations towards certain foods have been handed down through generations. Today this causes difficulties in promoting transitions, e.g through introducing a more profound perception of soybeans as valuable good, intended for *well balanced/nutritious/healthy/...* human diets (Eggler 2010, 135).

Nevertheless, after lupin, soybean continues to be the largest source of plant-originating protein used for human consumption. More precicely put it ranges between 34 to 48% in processed end products (Kumar et al. 2010, 376).

However, up to this day, meat and other animal products remain the number one protein source on a global level (EIP et al. 2014a, 4 and Keating et al. 2014).

Apparently though transitions take time and they cost money (Pretty 2005, 10f.). Moreover *food-choices,* including decisions about meat consumption, are embedded in highly complex socio-economic and demographic structures. Therefore the type of meat consumed as well as the regularity of meat consumption are country-specific and influenced by gender, religion, status, ethnicity and cultural rules and standards, making it difficult to single out specific reasons for transitions (Vranken et al. 2014).

On a global scale diets tend to get richer in unsaturated fats, sugar and salt, but decrease in unrefined carbohydrates (Sage 2013 and Tomlinson 2013). Above all there are strong tendencies towards amplified meat-based diets by a considerable share of people in *emerging economies* (Lal 2013) such as in China, India, or Mexico (Allouche 2011; Lal 2013 and Tomlinson 2013). Similar developments are reflected in production statistics e.g. from swine industries, which registered an increase of almost 50% (from 14.2 m tons 1961 to 27.2 m tons in the year 2012) (FAOSTAT, as cited in 2014b Seifried 2014, 23f.), poultry industries, which six-fold (2.9 m tons in 1961 to 17.7 m tons in 2012), as well as beef production industries, which increased from 9.7 m tons in 1961 to 10.4 m tons in 2012 (FAOSTAT, as cited in 2014b Seifried 2014, 23f.).

This lead to a projected global rise in meat production from currently 308 m tons in 2013 to an estimated 500 m t in 2050 (Heinrich Böll Stiftung et al. 2013). Bearing in mind that such increases go along with rising needs for acreage for feeding materials as well (mainly maize and soybean) (Heinrich Böll Stiftung et al. 2013 and Seifried 2014, 23f.), as well as increased demand in actual grain (Lal 2013). Consequently there might be enhanced demands for limited resources (including grain, maize and soybean) for the livestock industries pushing price levels (Heinrich Böll Stiftung et al. 2013 and Seifried

2014, 23f.). Such developments further enhance the need for transportation, demand in energy and subsequently raising greenhouse gas emissions (Dara et al. 2015; Lal 2013 and VCÖ 2014, 38).

Besides the debate surrounding global diets and meat consuption patterns in particular is somewhat delicate since there seems to be a common understanding not to interfere with shifting diet patterns in the Global South. This includes the necessity to redirect diet patterns in the Global North (Tomlinson 2013). With the vast scale of the topic on *global food security* per se (and all the challenges going along with it) beeing [...] *discursively constructed on the basis that the imperative to meet the projections of increasing demand, based on the dietary choices of an increasing, wealthier, population in the Global South is taken as a given.* (Tomlinson 2013). It is therefore believed that global food systems and the broad eld of *food security* (see following Chapter 3.1.4.2.2) need to be understood in more detail (Sage 2013 and Tomlinson 2013). Sage (2013) further suggests to apply *food regime analysis.*

Moreover it seems unsurprising that the topic of global meat consumption patterns and adjacent agendas are expected to become even more pressing, more controversial and subsequently lead to a stiring up of the already heated debates until 2050 (OECD/FAO 2014; VCÖ 2014, 37f. and Pretty 2005, 2). This projection further highlights how food is in fact a highly political topic (Schori et al. 2003 and Tomlinson 2013). It also emphasises the far-reaching implications of policy maker s decisions on various scales, including impact on global agricultural systems (Pretty 2005, 2) and food consumption patterns (Sage 2013). It also points out the importance of supporting them in the desicion-making process with scienti c data.

F*ood sovereignty* movements[35] on the other hand aim at bottom-up approaches that are deeply rooted in the communities. Allouche (2011) lists *food sovereignty* as an example of how the public critically questions global food trade- and water security systems. The movement targets sustainable approaches on *food security* for instance through rooting for agro-ecological technologies and local food production[36]. Most important however remains the support of small scale farmers, generating access to land as well as fair pricing.

Another example is the global social farmers movement *La via Campesina.* Through

[35]The food sovereignty movement in Austria is termed Nyéléni Austria, named after a place in Mali, Africa where the movement was initiated (www.ernährungssouveränität.at/nyeleni/, last accessed on 14.07.2015)

[36]It may be pointed out that there is not one legal definition of the term *local food* production. In general *local* is thought of as food that was cultivated and offered for selling in a comparatively small area of about 50 km (30 miles) (Kirwan and Maye 2013).

introducing the idea of *food sovereignty* at the 1996 World Food summit this movement has risen to a strong advocat opposing industrial and neoliberal forms of agriculture (Allouche 2011 and Tomlinson 2013).

> The movement de nes food sovereignty as the *"[r]ight of peoples, communities, and countries to define their own agricultural, labour, fishing, food and land policies, which are ecologically, socially, economically and culturally appropriate to their unique circumstances. It includes the true right to food and to produce food, which means that all people have the right to safe, nutritious and culturally appropriate food and to food producing resources and the ability to sustain themselves and their societies* (Glipo and Pascual, 2005, p. 1, as cited in Tomlinson 2013).

Values promoted by various advocates would also need to be re ected in the consumer s behaviour in order to lead to change. In reference to a workshop in the UK Kneafsey et al. (2013) reported that participants were well aware that accessibility to food is strongly rooted in monetary possibities of individuals. Access is thus gained through money. People with less nancial exibility are consequently confronted with restricted abilities in making food choices, accessability to food itself as well as limiting in uencial power as consumer. In the same way Kirwan and Maye (2013) stress the importance of helping people to understand the signi cance of *"[...] tak[ing] ownership of their food [...]"* (Kirwan and Maye 2013). E orts are made to educate consumers about the origins of their food, as knowledge on the implications of consumer s behaviour on local food structures are vital to alter their behaviour. Therefore the authors stress the importance of communicating possibilities of supporting one s own community and local farmers in order to participate in shaping a well-functioning and healthy local food system (Kirwan and Maye 2013). In further extension this aims at creating educated, empowered and critical consumers in order to support long-lasting (sustainable) change.

However reports on food quantities needed to feed a growing world population mostly concur that overall food production will have to be enhanced. Additionally e orts in intensifying agricultural production levels have to be accomplished within the thresholds of existing acreage. Even though exclusively enhancing the production may only be one part of the solution which, standing on its own, would proof to be insu cient. Therefore adjacing topics on projections for future problems will have to target poverty[37] alleviation,

[37]The terms *poor* and *poverty* will not be defined and looked more closely upon in the framework of this master's thesis. It should be pointed out though, that these are terms found in political arenas

access to food or food shortage/hunger induced by poverty. Yet great concerns have been risen concerning newly evolving food systems to may not be able to reduce poverty induced food shortages in a more satisfactory way than existing ones. Relieve is hence aspired through developments in low-cost, service friendly and readily available technological solutions (Pretty 2005, 3f.).

Particularly small-scale farmers would need to rely on a certain exibility in upcoming solutions, marked for instance by aiming at an increase in local food production, a decrease in water- and land degradation and a support of sustainable agricultural systems (Pretty 2005, 3f.), because small-scale practicioners and sustainable farming systems in general need individually tailored solutions instead of one- ts-all concepts (Lal 2013, see also Chapter 3.1.4.2.5 on enhancing production levels). This requested exibility applies for example for small-scale alpine livestock farming environments. In the Alps a lot of areas are farmed solely with animal husbandry. Compared to agricultural sectors that cover signi cant industrial interests alpine livestock farming systems are frequently overlooked or neglected in cross ring debates on reducing meat production levels. However these farmed landscapes would otherwise be lost, simply because they are unsuitable for planting or implimentations of alternative cultivation systems (Eggler 2010, 38 and 40f.). Another example is the simultaneous use of mixed livestock-crop production systems which are commonly implemented by small-scale farmers all over the world. Additionally it may be worth mentioning that farming systems like these account for half of the world s total production quantity in food stu (Lal 2013).

Moreover mixed agricultural systems often function in ways aligned with the concept of *sustainable intensification*[38], as fertilizer- and water inputs need to be used in a reasonable way in order to improve harvests and net private incomes of the farmers, while minimising waste (Lal 2013 and Uri 2000). The signi cance of waste and storage management on agricultural products thus need to be acknowledged (Keating et al. 2014; Kirwan and Maye 2013 and Misselhorn et al. 2012), as they simultaneously reduce the need for additional yields (Keating et al. 2014).

For example today s research results suggest that global edible crop harvests would

with huge international organizations as key actors. Personal literature recommendations on poverty include authors such as Martha Nussbaum, Amartya Sen and Clemens Sedmak.

[38] The term *sustainable intensification* aspires to improve yield per unit land when at the same time social, political and environmental impact should be considered and costs for resources and influences on communities and environments should be kept at a minimum and are more or less coherent with the sustainability concept (Bennett et al. 2014). Furthermore the concept includes adaptations in crop management practices (e.g. no-till, see Chapter 3.1.2.4 on tillage systems), agroforestry systems, cover cropping, precision farming or integrated nutrient management and irrigation systems (Lal 2013).

need to be in the range of roughly 4600 kcal per person per day. However this required amount in kcal is reduced due to loss related to harvest, suboptimal distribution of food and waste. The actual amount available for consumption was consequently estimated to be about 1400 kcal. Reducing loss that occurs post-harvest may therefore be an equally important goal as enhancing yields (Tomlinson 2013).

Until the year 2050 a 50% decrease in food waste was reported to be a rational goal (see the Foresight, 2011, 19, as cited in Tomlinson 2013). If an implemented strategy would achieve this target, the 50% reduction was estimated to account for an additional reduction in yield production quantity by an amount equivalent to 25% of today s total food production (Tomlinson 2013). Supplementary grassland management strategies, particularly in arid and semiarid regions, are currently expected to have great potential in reducing global yield requirements as well (Lal 2013).

Latest political discussions (namely in the UN) reveal a trend of related subjects to emerge in an increasing amount under the patronage of the term *agro-ecology.* This concept describes the fusion between *"[...] apply[ing] ecological concepts and principles to the design and management of sustainable food systems"* (Gliessman, 2007, 369, as cited in Tomlinson 2013) in a scienti c way. Further agro-ecology aims at *[...] meeting people's need for food which gives equal attention to the goals of sustainability, resilience and equity and not only to production"* (UK Food Group, 2010, as cited in Tomlinson 2013).

However access to land, especially by small-scale producers, constitutes one of the major aspect topics that will need to be addressed and discussed more urgently. This aspect was highlighted by former UN Special Rapporteur Jean Ziegler, but is re-emerging and greatly stressed in the concept of *agro-ecology,* the *La via Campesina-* and the *food sovereignty movement* as well (Allouche 2011). To further emphasise the importance of this aspect Cupples (1992) states that *"[l]and is the essence of survival, and in an agro-economy, land is economic and political power, and those deprived of it are deprived of any form of participation in the political decision-making process".*

> Another quote reads *"[l]and issues are of crucial importance to economic and social development, growth, poverty reduction and governance. [...] Land tenure closely binds issues of wealth, power and meaning. [. . .] Secured and increased access to land and natural resources for the landless and land-poor families is a key means of achieving food security and broadening the economic opportunities available to them"* (http://ec.europa.eu/development/Policies/-9Interventionareas/Ruraldev/rural/landpolicy_en.cfm, as cited in Broegaard 2008, 2).

3.1.4.2.2 Food security The concept of *food security* arose in national and international policy debates as a reaction to the so-called *global food crisis* (Kirwan and Maye 2013 and Tomlinson 2013) and was characterized by growing demands on limited resources which further increased pressure. The concept was thus introduced in the light of a growing population, increasing inequalities and progressing climate change (Deryng et al. 2006; Schneider et al. 2011 and Tomlinson 2013) and in times when people in the Global South were already unable to a ord staple foods. This nurtured the fears of an upcoming crisis and the urgency to enable agriculture to an instantaneously increase of calories produced in order to feed *"[...] the hungry [of] tomorrow* [...] (Nally, 2010, 45, as cited in Tomlinson 2013).

However despite the commonly believed outstanding connections between crisis/war, poverty and limited resources, greater potential for an arising con ict generally result from extremely poor and extremely rich living side by side. Moreover possible richness poses immensely greater potential for crisis than de nite poverty (Münkler 2004, 17). Similarly Allouche (2011) points out that even though con icts that appear to arise in situations of insu cient resources and may indeed be linked to water insecurity, hunger or malnutrition would nonetheless rst and foremost re ect policies of inequal allocation.

By facing already restricted resources this *new green revolution* must of course be implemented without extending existing farmland (Tomlinson 2013) as well as preserving other resources, namely water (Schneider et al. 2011 and Pretty 2005, 3f.). Despite the necessity to substantially enhance production levels this view is (by far) not accepted to be a given (Tomlinson, 2011, 2, as cited in Kneafsey et al. 2013, see also Chapter 3.2 on the outlook). The task of increasing yields in order to sustain livelihoods without expanding acreage while keeping negative environmental impact and resource use down to a minimum was termed sustainable intensi cation[39] (Godfray et al., 2010, 2776, as cited in Kirwan and Maye (2013), see also Lal 2013, Pretty 2005, 3 and the Royal Society, 2009, as cited in Kirwan and Maye 2013).

The de nition of food security itself dates back to the 1970s (Kneafsey et al. 2013). Back then propositions were made especially to *poor countries* who needed to deal with *hunger*[40] and who consequently often decided to pursue in the strategy of investing in grain

[39]Further detail on the term *sustainable intensification* is given in footnote 38.

[40]Malnutrition, undernourishment and undernutrition are sometimes used synonymously and are difficult to distinguish due to obscured utilization. FAO defines *undernutrition* as a result from undernourishment, possibly in combination with low ability of the body to absorb or use taken up nutrients. Undernourishment could therefore be considered as a cause of poor health. Undernutrition further includes a possible imbalance between dangerously little weight for one's age/tallness, as well as a lack in sufficient vitamins/micronutrients, e.g. resulting in stunted growth. *Undernourishment* on the

reserves in order to enhance national self-su ciency (Kneafsey et al. 2013). Especially in the UK food security is mainly used in this initial meaning. Another often quoted de nition was given by Maxwell (1996, 155, as cited in Kirwan and Maye 2013), who aspired a more individual meaning on the household level and who relocated the focus and stronger emphasised on one s ability to get access to food in the global market. He also pointed out the signi cance of food availability (Kneafsey et al. 2013 and Kirwan and Maye 2013) in due course of the slowly evolving, but dominating, neoliberal political ideology. From a neoliberal point of view the policy of relying on national grain reserves (especially in *poor countries,* as initially aspired) should be entirely replaced by a policy relying on exports and an opening of the agrarian sector to prices on the world market (Kirwan and Maye 2013).

Later, with the upcoming de nition of the World Trade Organisation (WTO), the emphasis of food security was developed further. Priorities of the WTO were placed on national markets which should support and promote a self-su ciency approach with regards to basic foodstu (Kirwan and Maye 2013). Today s most popular de nition on food security was given by the 1996 World Food Summit which basically states that all people should have access to su cient, safe and nutritious food at all times. Further people should be enabled to lead healthy and active lives (see WHO, 2011, as cited in Tomlinson 2013). A more recent de nition used by the United Nations Food and Agriculture Organization (FAO, as cited in Nowotny 2014, 8) on the other hand reads as follows

> *"[a] situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution or inadequate use of food at the household level. Food insecurity, poor conditions of health and sanitation and inappropriate care and feeding practices are the major causes of poor nutritional status. Food insecurity may be chronic, seasonal or transitory".*

The FAO additionally categorizes food (in)security into seasonal, chronic or transitional condition (Nowotny 2014, 9). In summary, the concept has developed since the 1990s and

other hand describes a situation in which a person aquires insufficient food to meet defined dietary energy demands for at least one year. FAO further defines *malnutrition* as an irregular physical condition which is caused by unsuitable or imbalanced consumption patterns of micro- or macronutrients (noteworthy is probably that excessive uptake is also included). United Nations relate malnutrition also to *hidden hunger* (Nowotny 2014, 6ff.).

now covers a range of aspects such as food production, food consumption and interlinkage with di erent environments. (Nowotny 2014, 8)

3.1.4.2.3 The often-cited 50-70% production rise Allouche (2011) writes about the [...] *so-called age of uncertainty* [...] in which NGOs, key international organisations and individuals as well as the media spread highly alarming notions. Examples include scarcity of water which would lead to mass migration or con ict/war over water/food. In spreading such scenarios (e.g. by the media), threats and fears are being exploited and serve the purpose of e.g. justifying the declaration of water/food as key policy priorities on a global scale (Allouche 2011)[41] entailing potential consequences to protect them.

Currently dominant key institutions and individuals claim that global food production needs to be doubled by 2030 and enhanced by 70% in order to *"[...] feed the 9 billion*[42] *[...]* (Tomlinson 2013), a statement which was even repeated by some scientists (Tomlinson 2013). These gures have become not merely prominent but omnipresent. They are used not only in o cial documents, but also by in uencial individuals and institutions. Those statistics have thus somehow evolved to gures everybody accepts and repeats (Tomlinson 2013).

For example the 70% gure plays a major role in de ning today s UK policy within international debates concerning food security. Tomlinson (2013) therefore examined intentions connoted with these statistics and elaborates on two observations. First, she points out how high increase in production like the stated 70% are never meant to become a normative goal of policy. Second, following through with a target like this according to her would lead to an aggravation of malfunctions already found in today s global food system (Tomlinson 2013).

Besides the stated percentage does not refer to an extension of actual tonnes of yield but to the *"[...] aggregate volume of demand and production of the crop and livestock sectors [...]"* (Tomlinson 2013). The latter consists of a multiplication of physical quantities of either production or demand by the cost of the commodity and represents a certain way of calculation. Characteristics of this way of calculating would support subsequent presumptions. For instance, a change in commodity types would be entailed, towards more meat and products related to animal husbandry and away from *staple foods.* Such

[41] Elaborations on the worldpress and the media as exploited tools in asymmetric/new wars are given e.g. in Münkler (2004, 158f.).

[42] Referring to the expected population increase of up to 9.2 billion in 2050 (Lal 2013; Sage 2013 and Tomlinson 2013) and to theneed of increasing the production level in order to feed globally growing population (see also Kneafsey et al. 2013).

a cost-based index would also grow faster than the equivalent aggregate in physical units. Additionally if the calculation is based on actual yields, the gure would be slightly lower, at roughly 64% instead of 70%. Moreover vegetables and fruits are excluded from this way of calculation. This is partly due to the FAO statistics not treating vegetables as commodity crops. The measure unit deriving from the standard measure unit of the FAO is calculated in food consumption in calories per capita. This is based solely on the supply-side *availability criterion* which is very useful in broad geographical estimates, but according to Tomlinson (2013) it would not include waste and unbalanced use of food throughout the population (Tomlinson 2013).

However the FAO does not explicitly state an enhancement of 50 or 70% by 2050. Instead those gures are stated to express the author s opinion of the most likely scenario. Tomlinson (2013) thus suggests to keep in mind how statistics using the 50-70% gures are actually being exploited as *"[...] key discursive device [...]"* (Tomlinson 2013).

3.1.4.2.4 The Malthusian concept vs. emphasising local, small-scale structures and the importance of language use There is a large ongoing discussion about whether it is more bene cial to increase or to decrease trade liberalisation to induce an ampli - cation in aspects related to food security (Kirwan and Maye 2013). Sage (2013) for example argues that the use of *the 50% figure* would be instrumentalised with the intention to link considerations of food security with neo-Malthusian ideas in order to fortify neoliberal assumptions. Such *scaled definitions* (Jarosz, 2011, as cited in Kirwan and Maye 2013) would be used e.g. by the agro-industry but could also be found in policy texts of FAO and World Bank. The introduction of such argumentation lines would aim at maintaining or intensifying existing modes of production or further push sustainable intensi cation[43] (Kneafsey et al. (2013)). Structural Adjustment Programmes (SAPs) of the World Bank for instance would target at broader liberalisation of trade and an opening of markets to extend international import levels. Currently agreements of the World Trade Organization (WTO) reveal an increasing focus on the Global South in matters relating to bene ts and obstacles of trade liberalisation in agro-policy (Allouche 2011 and Paasch et al. 2010, 121). This is a rather recent development and research on the topic seemingly places a strong emphasis on protective measures of *the poor* against impact caused by trade liberalisation. Although results need be awaited (Allouche 2011).

However structural adjustment strategy programmes rididly push towards an opening of national markets in countries of the Golbal South. As it so happens this strategy is

[43]Further detail on the term *sustainable intensification* see Footnote 38.

an integral part of structural adjustment strategy programmes and consequently a non-negotiable. This circumstance forces countries to accept cheap imports e.g. of certain staple foods, which occasionally coincides with poor chilling chains, evoking additional risk (Paasch et al. 2010, 121).

A ected products may be o ered at lower prices than locally grown equivalents which leads to an extensive intensi cation of production. Moreover this leads to an emphasis of processing (few) selected goods which may be exported at particularly low prices which Paasch et al. (2010, 121) revealed as practiced *dumping*. Consequently long-term investments e.g. in agricultural machinary drastically decrease. This further shortens the capabilities of producing staple foods on a local level. Apparently investments in machenery/... would be exactly what would enable locals/the poor/... to maintain the national level of subsistence which was known before the trade liberalisation (Paasch et al. 2010, 121).

Moreover investments to continue pushing industrialisation push nations into making debts with the purpose to pursue a growing purchasing power of households. Such strategies are intended to enable citizens to buy food on international markets rather than living o their own property or supporting local food production. According to Jarosz (2001, as cited in Kneafsey et al. 2013) such developments support veiling structural causes of hunger. Additionally responsibilities to act upon poverty and food security are strongly passed on to the individual and household level[44], consequently shifting away from the

[44]At the congress titled *Gutes Leben für Alle* (loosely translated as *good life for all*) held on the 20th-22nd of February 2015 at the Vienna University of Economics and Business, Shalini Randeria spoke about modern nations. Shalini Randeria is Rector of the Institute for Human Sciences (IWM) and currently Professor and Chair of the Department of Social Anthropology and Sociology at the Graduate Institute of International and Development Studies in Geneva,

She stated that nations would be rigid and quoted the view about the *externalisation of production* (Shalini Randeria, February 2015), in which industrial nations would distort prices and hence create a tilt at the world market. She also illustrated the general picture of how nations would mime to be quite weak and unable to act, because they are politically unwilling to act andotion that the magnitude of anything *local* is sufficient to qualify it as being beneficial. Local would therefore automatically imply *better*. For example a food systems would be *more democratic*, *more sustainable* and *unquestionably more desirable* if it would be local, compared to any other magnitude of operation, which is often additionally corroborated by the argument of long transportation distances covered by food. Consequently a critical mindset should be kept (does local result in higher benefits in this specific case) in order to evade running the risk of ignoring e.g. the political embedment and power relations in the specific scenario (Kirwan and Maye 2013, see also Millenium Ecosystem Assessment et al. (2005, 226)).

> "*Approaching these issues collectively quickly reveals that productivist, high external-input agriculture producing for distant markets is less likely to resolve the essential vulnerability of food insecure populations. Rather, it is about designing food production capabilities that enhance resilience, can foster adaptation to changing circumstances and contribute to mitigation*" (Sage 2013).

human rights approach[45] (human right to food[46]).

However in some cases intensi ed international trade is actually bene cial. For instance in arid or semi-arid regions it is believed that enhanced trade liberalisation would increase food security because in this setting new/alternative possibilities for additional income are di cult to be found or created due to limited local agricultural production potentials (Allouche 2011 and Tomlinson 2013).

Other researchers on the other hand encourage international trade and promote it as strategy to enhance food security. They argue that this strategy would lead to a spreading of the risks as in the event of yield loss in one region yield from other production sites would still be readily available. This view is in accordance with the FAO de nition on food security (de ned in the 1996 World Food Summit[47]) and states that *[a]lthough it*

This is why the Millenium Ecosystem Assessment et al. (2005, 226) suggest to supplement local strategies with integrated measures on regional and global scale, such as treaties, in order to assure common resource management strategies. Consequently modes of production, consumption patterns and aspects related to the well-being are generally interlinked, as transitions usually take place between regions. In a functioning ecosystem all of these aspects are co-depending on economical- and social ties alike. As a result it was suggested to intensify efforts in building adaptive governance systems (Folke 2006) and to encourage new and creative ways of public policy making with regards to food and livelihood security (International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), 2009, as cited in Sage 2013). how they would obscure responsibilities by shifting towards an elected administration, making it very difficult to find out who is actually responsible for what. Transparency is therefore missing and citizens who would like to express their discomfort would not even know where exactly to complain. Shalini Randeria calls such nations *listige Staaten* (loosely translated by the author as *cunning states*).

[45] In her Master's thesis, Katharina Nowotny states that due to permanently evolving ideas about human rights in combination with a lack of an officially accredited definition, it is difficult to define *human rights* in a general way. In her thesis she offers examples of possible definitions by Matthias Koenig, K. Peter Fritsche and Manfred Nowak and how they are to be separate from fundamental rights, civic rights. After World War II, the term *human dignity* arose, which includes dimensions of freedom, equality and humanity. In addition human rights should be universally applicable (Nowotny referred to the definition of Dieter Sienknecht and critical arguments of Arnd Pollmann and Manfred Nowak) (Nowotny 2014, 14ff.).

She also emphasised *human rights* to be quite a controversial concept e.g. due to tensions between protection of international human rights and national sovereignty; contradicions between certain human rights, how they are compatible with democracy or applicable to the diversity of cultures. Therefore universally applicability is most controvers especially due to the concept of *human rights* deeply rooted in european/western ideas, causing contradictions and incompatibility to an application in other cultures (Nowotny 2014, 21).

[46] United Nation's special rapporteur Jean Ziegler stated that *"[...] the right to food is the right to have regular, permanent and unrestricted access, either directly or by means of financial purchases, to quantitatively and qualitatively adequate and sufficient food corresponding to the cultural traditions of the people to which the consumer belongs, and which ensure a physical and mental, individual and collective, fulfilling and dignified life free of fear*" (Jean Ziegler, http://www.ohchr.org/EN/Issues/Food/Pages/FoodIndex.aspx, accessed last on 23rd may, 2015).

[47] The 1996 World Food Summit from the FAO (as cited in Allouche 2011) states that *"[...] all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their*

has been acknowledged that free markets usually penalize the poorest who have the least influence on how global markets are structured and regulated (see Anderson, 2009 and Aksoy and Beghin, 2005, as cited in Allouche 2011).

However, rising food prices and increasing di culties in maintaining livelihoods when running a farm is a consideration (Kneafsey et al. 2013) which is believed to bring in new perspectives, as the discussion on food security thus gets interwoven with topics on hunger. Tomlinson (2013) on the other hand states that such ties would be originating in Malthusian ideologies too deeply and would hence be unbene cial in encouraging a *thinking outside the box* (indicating a *flat key*[48] , Mooney and Hunt, 2009, as cited in Tomlinson 2013).

Whereas targeting questions concerning starvation by lack of access (Sen, 1981, as cited in Tomlinson (2013), see also Allouche (2011)) may encourage developments and thoughts about alterations of existing modes of food production (indicating a *sharp key* (Mooney and Hunt, 2009, as cited in Tomlinson 2013)). In addition Tomlinson (2013) highly suggests relating concepts and disciplines (such as ecological food provision, *food sovereignty*, and *agro-ecology*). She further stresses the importance of using and applying language to frame analysis (Tomlinson 2013).

In summary interdisciplinary approaches and stronger focus on language (see also quote from Marlene Streeruwitz, 1) would be bene cial in creating a setting that allows for something new and transitional (*sharp key*). This would further encourage changes towards a more sustainable agriculture (Tomlinson 2013) which itself aims at preserving the environment for future generations in combination with a social transformation. A change in the social sphere would particularly entail enhanced levels of democracy and egalitarian forms with a simultaneous focus on national food self-su ciency. Self-su ciency on the other hand should best be characterised through low technology and low cost inputs, but would be high in required labour intensity (Tomlinson 2013).

Similarly Gottwald (2010, 147) states that

> *"[...] the stipulation that an eco-social structuring of the future of alimentation [...] must take the principle of subsidiarity seriously, making sure that*

dietary needs and food preferences for an active and healthy life [...]".

[48] Mooney and Hunt (2009, as cited in Tomlinson 2013) established food security to be a master frame, consisting of three claims of ownership (*collective action frames*) to food security as a social problem: a) food security as hunger, b) food security as part of a community's development and c) *food security* as minimizing risk. Within a) to c) Mooney and Hunt singled out *sharp* and *flat* keys -with a *sharp keys* indicating turnarounds through crisis and critical developments in dominant institutionalized developments and *flat keys* indicating reinforcements of institutionalized performances.

> *state as well as civil society activists or higher organizations limit their activities to support and refrain from interfering with supply, distribution, or trade challenges".*

Counter weights to these developments are presented in agricultural production systems which are based on the concept of agro-ecology. This concept o ers considerable potentials that are worthy of being aspired as they particularly support small-scale farmers. However, despite the potential of the concept, it is only gaining limited recognition (Sage 2013).

Consequently Tomlinson (2013) argues that even though there might be plenty on a global scale, this does not necessarily lead to a trickle-down e ect (reaching the local scale). Besides an accelerated development and an increased focus on local agriculture would entail two diametrical approaches found in the Global South. Countries have thus developed into major cash crops exporting production machines urged to predominantly deliver high quality cash crops. These goods were cultivated on the most fertile sites in large scale production systems (e.g. monocultures) which resulted in pushing small-scale or subsistence farmers even deeper into tenuous forms of existence (Tomlinson 2013).

Studies on the UK food supply sector highlighted the high degree in global cross-linkages in today s UK principal food sector (and its supply chain). Furthermore challenges about sustainable food production and issues targeting the a ordability of food need to be discussed on a global level. It would therefore be in the UK s best interest to work towards a functioning and e ective global food market. However it was reported that a vivid domestic agricultural sector would be a crucial contribution for a reliable, solid food system in the UK. In a 2009 House of Commons Environment, Food and Rural A airs Committee (House of Commons, 2009, as cited in Kirwan and Maye 2013) the UK government even reported that UK would nonetheles continue to rely on multiple globally spread food markets in order to di use the risk, rather than focussing stronger on domestic food production and increasing UK s self-su ciency (Kirwan and Maye 2013).

Allouche (2011) counters that rising food prices, land grabbing issues and movements such as food sovereignty would illustrate boundaries of today s international water- and food systems with regards to guaranteeing stability, resilience and sustainability.

Latest research would clearly ignore how land-grabbing would mostly be related to issues concerning water. For expample nations that su er water shortage additionally have to rely on imports of foods, because they lack in su cient water to grow them themselves. Consequently these nations strongly push for the strategy to rely on investments in agricultural land elsewhere in order to support crop cultivation for domestic use somewhere abroad to relieve the tensed water situation *back home*. Outsourcing such water-supplies for food production would also pose risks. They might not be visible at first, or would only show with time delay, but offering water sources and fertile land for *the highest bidder* (Allouche 2011) should be kept at close watch, even though up to now it has most frequently been ignored (Allouche 2011).

International trade consequently supports the disguising of water availability on a global level, as countries rich in water supply are capable of exporting more water-intensive goods. This phenomenon was termed *virtual water* (Allouche 2011) and was also suggested to steer on water scarcity in other regions (Allouche 2011), subsequently impacting global farming systems. This would further lead to a gradual shift away from small-scale production units with few inputs (e.g. fertilizer), towards few large scale entities that would be rich in power, rely on high purchasing power and would be based predominantly on high input levels (Ghosh, 2010, as cited in Tomlinson 2013).

Countries relying on cash-crop production are likely to (need to) import basic food stuffs (Allouche 2011 and Tomlinson 2013) and are reported to rely stronger on imports of cereals, livestock products, vegetable oils and sugar. Consequently they are continuously floating away from self-sufficiency. Moreover a dramatic increase in the vulnerability occurs due to the alternating pricing on export goods which then are linked to global markets with fluctuating currency exchange rates (Tomlinson 2013).

Therefore it is advised to aim at greater balance between export and import in order to enhance food sovereignty and consequently increase food security (Tomlinson 2013, see also Millenium Ecosystem Assessment et al. (2005, 226)).

Strengthening local food production systems is therefore often stated to be crucial (Allouche 2011). Kirwan and Maye (2013) nevertheless stress the danger of getting tangled up in the so-called *local food trap* (described by Born and Purcell, 2006, 195, as cited in Kirwan and Maye 2013). This phenomenon refers to the seemingly implicit notion that the magnitude of anything *local* is sufficient to qualify it as being beneficial. Local would therefore automatically imply *better*. For example a food systems would be *more democratic*, *more sustainable* and *unquestionably more desirable* if it would be local, compared to any other magnitude of operation, which is often additionally corroborated by the argument of long transportation distances covered by food. Consequently a critical mindset should be kept (does local result in higher benefits in this specific case) in order to evade running the risk of ignoring e.g. the political embedment and power relations in the specific scenario (Kirwan and Maye 2013, see also Millenium Ecosystem Assessment et al. (2005, 226)).

> *"Approaching these issues collectively quickly reveals that productivist, high external-input agriculture producing for distant markets is less likely to resolve the essential vulnerability of food insecure populations. Rather, it is about designing food production capabilities that enhance resilience, can foster adaptation to changing circumstances and contribute to mitigation* (Sage 2013).

This is why the Millenium Ecosystem Assessment et al. (2005, 226) suggest to supplement local strategies with integrated measures on regional and global scale, such as treaties, in order to assure common resource management strategies. Consequently modes of production, consumption patterns and aspects related to the well-being are generally interlinked, as transitions usually take place between regions. In a functioning ecosystem all of these aspects are co-depending on economical- and social ties alike. As a result it was suggested to intensify e orts in building *adaptive governance* systems (Folke 2006) and to encourage new and creative ways of public policy making with regards to food and livelihood security (International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), 2009, as cited in Sage 2013).

3.1.4.2.5 Enhanced production, affordability, allocation and access Moreover the general logic behind a physical lack of food availability (insu cient production) is the believe of having to enhance yields (Allouche 2011 and Tomlinson 2013). However this simplistic notion seems to somehow con rm the idea, that an increase in food production would automatically result in a [linear] reduction of hunger. A similar misconception is applicable with regards to water (Allouche 2011). Origins would mostly be connected to *politics of inequality* (Allouche 2011) instead and would further be overshadowed by insu cient access, utilisation and distribution to a ordable *appropriate* food on a regular basis (after Barrett, 2002, also FAO 2009, 14 as cited in Tomlinson 2013, see also Kneafsey et al. 2013 and Kirwan and Maye 2013).

Appropriate food refers to the perception that global hunger is not a problem of abrupt starvation, but a barely noticeable, steady process of malnutrition. Once set in motion higher susceptibility to diseases would subsequently follow and would prevent people from *"[leading] active and productive lives* [...] (Allouche 2011).

Appropriate economic access and appropriate food therefore include monetary and non-monetary opportunities to obtain enough (amounts) as well as su ciently nutritious food (Allouche 2011 and Kneafsey et al. 2013). Besides it also includes the classi cation of social and cultural ascribed issues in respect of the *"[...] acceptability of certain types of* *food* [...] (Kirwan and Maye 2013).

Consequently *availability* by itself does not improve the nutritional situation of individuals (Allouche 2011; Misselhorn et al. 2012 and Sage 2013). As Amartya Sen (1981, as cited in Allouche 2011, see also Kneafsey et al. (2013)) so famously points out, even in times of food shortages wealthier households would scarcely su er hunger, whereas poor households would frequently keep being hungry even during times of plenty.

In summary mere production raise or enhanced food supply would neither solve the issue of food security_(Tomlinson 2013 and Kneafsey et al. 2013), nor lessening hunger and malconsumption or starvation (Allouche 2011; Sage 2013 and Tomlinson 2013).

Inequality in contrast would comprise the main reason for limits in water- and food security. This further concludes that water/food security issues would be primarily political problems. This perception would add barriers and would ultimately call for growing political democratisation (Allouche 2011).

3.1.4.2.6 Believe in relieve through technical innovations Opinions on the degree of relief on feeding the world population in 2050 due to technical innovations are split into researchers stating a) that technical capacities and innovations will basically be su -cient, but that constraints in whatever form (economic/institutional/...) may still hinder su cient availability of agricultural produce (Mitter et al. 2014) vs. b) technological ndings and innovations are stated to be insu cient or not believed to be able to keep up with the expectations/their promises (Allouche 2011 and Tomlinson 2013, as for example printed by The Royal Society, 2009, 2011 as cited in Tomlinson 2013).

Tomlinson (2013) emphasises that *believing* in solutions, deriving from science or technological innovations in order to master imminent impact on the ecological sphere and resource-restrictions, may be tighter rooted in little trust placed in current solutions offered by policy makers. Nonetheless it would be the duty of policy makers to deal adequately with existing troubles of today s food system. However even notable scienti c publications (e.g. Nature, 2010 as cited in Tomlinson 2013) and meetings (e.g.The Royal Society, 2011, as cited in Tomlinson 2013) keep emphasising how intensifying the agricultural sector through technological improvements would be crucial (Tomlinson 2013) (further details on the topic are elaborated in the course of Chapter 3.2 on the outlook).

3.1.4.2.7 The *turn-over* in diets in the face of climate change According to current predictions an intensi cation in the share of animal husbandry in countries of the Global South is to be expected. A shift like this would ultimately impact our climate. For example, livestock currently accounts for 14% of global greenhouse gas emissions, although speci cs remain uncertain (Intergovernmental Panel on Climate Change (IPCC), as cited in Tomlinson 2013).

Moreover projections for emissions originating from agriculturally farmed soil exclude changes in emission levels that derive from *land-use changes* (see Chapter 3.2 on the outlook). However it is important to keep the constantly rising numbers in livestock farming as well as increasing deforestation rates in mind. Furthermore enhanced numbers in animal husbandry subsequently lead to higher needs in extra pastures and additional feeding materials. Current predictions on greenhouse gas emissions are consequently likely to be exceeded (Tomlinson 2013). Moreover additional knowledge is required on topics related to climate change and land-use change, as well as interrelation with environmental water ows (Allouche 2011). Furthermore global cropping patterns are tightly correlated with climate change. At a regional level this connection is highlighted particularly at times when the availability of water may restrict food production. Initiatives such as *water for food* or *crop per drop* may serve as illustrating examples. Current research however points out how su cient and consistent data on the topic, which is still scarce, would enable policy makers to come to knowledge-based decisions (Allouche 2011).

A more radical strategy to avoid a further rise (or even support a reduction) in greenhouse gas emissions by 2030 the Fourth Budget report of the Committee on Climate Change suggests a re-balancing in diets (Climate Change Committee, 2010; see also Audsley et al., 2010, p.18, as cited in Tomlinson 2013). However reducing the meat-consumption level while simultaneously pushing towards a nutritional transition is a process which is highly linked to the consumer s behaviour (Sage 2013). An aspired change in food-related cultural aspects must consequently be expected to take place very slowly and steadily. Moreover it will very likely be an incredibly di cult task to begin with (Godfray et al., 2010, as cited in Tomlinson 2013, see also Chapter 3.1.4.2.1 on food as cultural heritage).

Currently changes in food consumption patterns are thought to be initiated through strong advertising and constant promotion (even in research) of health bene ts correlated with reduced meat consumption levels (Tomlinson 2013).

3.1.4.2.8 Resilience and Socio Ecological Systems (SES) Origins of the *resilience* concept are found in material sciences and eco-social sciences (Sedmak 2013, 16f.).

Almås and Campbell (2012, 7) for example referred to Ostrom s (2009, as cited in Anderies and Janssen 2013) Socio-Ecological Systems (SES) framework in which adaptions would occur as reactions to disturbing signals. Their *resilient* character would enable them to most likely overcome crisis or heavy impact. Another visualisation of *resilience* would for instance be the ability of owering and growing despite sub-ideal conditions as well as the ability of materials or systems to absorb abrupt impact without loosing the initial structure (Sedmak 2013, 16f.).

To be more precicse the fundamental idea is found in the seminal paper of the ecologist Crawford Stanley Holling[49], whose de nition of resilience from 1973 became a classic and reads as follows: resilience is *"[...] a measure of the persistance of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables* [...] (C.S. Holling, 1973, as cited in Sedmak (2013, 16f.)[50], Gallopín (2006) and Folke (2006)). However current literature mostly uses the de nition of Walker et al. (2004) which states that resilience is *"[...] the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks."* (Walker et al. 2004). The latter de nition further refers to *"[...] stay[ing] in the same basin of attraction [...]"* (Walker et al. 2004, as cited in Gallopín 2006).

Today s most recent and often quoted de nition derives from Boyd, E. and Folke, C. (2012, 266, as cited in Nowotny 2014, 48) and states that

> *"[r]esilience is the ability to reorganise following crisis, continuing to learn, evolving with the same identify[sic] and function, and also innovating and sowing the seeds for transformation. It is a central concept of adaptive governance. The concept allows us to raise questions about what are the features of institutions that allow them to adapt or transform towards social-ecological sustainability“* (Boyd, E. and Folke, C., 2012, 266, as cited in Nowotny 2014, 48).

Consequently a system (i.e. the system *earth/people/...*) is never static but constantly evolving even throughout a disturbance (Folke 2006; Walker et al. 2004, see also Sedmak 2013). Research working in the operational sphere of resilience therefore acknowledges

[49] C:S: Holling, Resilience and stability of ecological systems. Annual Review of Ecology and Sytematics 4 (1973) 1-23

[50] (Sedmak 2013, 16f.) refers to further literature e.g. the collected volumes of Gunderson and Holling (L.H. Gunderson, C.S. Hollling, eds., Panarchy: understanding transformations in human and natural systems. Washington, DC, 2002) and from Gunderson and Pitchard (L.H. Gunderson, L. Pitchard, eds., Resilience and the behaviour of large-scale systems. Washington, DC.

In addition, in the article of Carl Folke (Carl Folke, Resilience: The emergence of a perspective for social-ecological systems analyses, Global Environmental Change (2006), 253-267), the concept of resilience is reviewed very much in detail.

this inherent aspect which allows the system to further develop (*renew, re-organize* (Folke 2006)) due to/during an impact. Accordingly it does not return to the exact point where it has been before the disruption, but returns to a slightly altered one. This aspect turns it into a *similar* system (after a disturbance), even though it might appear to be the same from an external point of view (Anderies and Janssen 2013). This slight but important distinction is why some researchers now prefer to characterise the apparently new system as being renewed, regenerated and re-organised when describing transformed characteristics of a system subsequent to an impact. However since each disruption cascades a multitude of heterogeneous responses, which in turn take their own time and way to react, predictions, e.g. on what future systems may look like, are rather hard or even impossible to make (Folke 2006).

Moreover such alterations also create opportunities and open up room for new developments or *regime shifts* (Gunderson, Peterson, & Holling, 2008; Holling, 1973, 1978, 1979; Holling & Gunderson, 2002; Ludwig, Walker, & Holling, 1997; Ludwig, Jones, & Holling, 1978, as cited in Anderies and Janssen 2013). Such regime shifts may result from (but may simultaneously be best described as) profound alterations of key drivers, causing severe developments within a system (Anderies and Janssen 2013).

Disturbances are therefore also expected to pose possibilities for more desirable outcomes as well, creating *adaptive capacity*[51] (Folke 2006). This however is an aspect criticised by IDS et al. (2012, 13) who state that the resilience approach would treat an impact and the re-structuring in an implicitly positive way rather than looking at these developments from a neutral point of view. Furthermore they emphasise how this argument would be particularly valid when applied on an individual or a household level. As counterexample they refer to a trade-o between an increase in individual resilience to be accompanied by a reduction in another trait such as self-esteem. In their opinion, increased resilience would hence coincide with lowered self-esteem.

IDS et al. (2012, 9) consequently argue that enhancing resilience on a household level in poor and vulnerable environments may come at a price, referring to a trade-o . More generally put the authors point out how despite being a highly applicable and desirable approach, the resilience approach may still come with curtailments. They also highlight how the approach would cover a large *multitude of scales* (IDS et al. 2012, 11), as it would be applicable on a global scale, in numerous disciplines, as well as on an individual

[51]The term *adaptive capacity* is explained further down in more detail and basically means the ability to cope or respond and adjust, even though those terms themselves are to be differentiated, as well (Gallopín 2006).

level.

In respect of the before mentioned trade-o s Anderies and Janssen (2013) con rm that, *"[...] such fundamental robustness-vulnerability trade-offs exist [...]"* even though, in their paper, the authors are referring to public political processes, uncertainties and disruptions that accompany these processes. With reference to trade-o s in political decision-making they also stress how there simply are no *fail-free policies* (Anderies and Janssen 2013). Therefore they suggest to target and aim at processes in the political sphere that create opportunities and open up spaces for learning, experimentation and adaptation and which allow room for an implementation of feedback loops (Anderies and Janssen 2013).

Sedmak (2013, 20) on the other hand points out how resilience would also entail the ability of developing and growing *because* of a crisis. By introducing the term *epistemic resilience* (Sedmak 2013, 20-34) connects resilience to identity (and therefore referring particularly to the individual level) and points out how identity would sometimes be questioned in the course of crisis. Moreover he argues that especially at times at which identity is questioned, resilience is needed, because in the just described context, crisis starts threatening integrity. Sedmak (2013, 34) therefore points out that

> *"Resilienz ist die Fähigkeit, Identitätsarbeit, Arbeit am Identitätsgleichgewicht trotz widriger Umstände zu leisten - und dabei sowohl im Sinne eines 'thriving' als auch im Sinne eines 'coping' zu gedeihen. Entscheidend ist dabei die Einsicht, dass resilient nicht die Person ist, die nicht berührt und verletzt werden kann, sondern die Person, die um die eigene Verwundbarkeit weiß und auch beschädigt werden kann. Der Begriff der Verwundbarkeit ist -etwa über das Konzept der Vulnerabilitätsfaktoren -eng mit dem Begriff von Resilienz verbunden* [52].

Moreover Sedmak (2013, 33-42) states that it is possible to manage certain crisis at one point in a resilient way while this ability might not reach such a high magnitude in a di erent matter, at a di erent time or vice versa. Sedmak therefore directly answers to the counter-arguments of IDS et al. (2012, 9).

[52] Loosely translated Sedmak (2013, 34) states that "*[r]esilience is the ability of 'identity craftwork', working on the equilibrium of the self, despite the lack of optimum conditions - and hence grow/flower in both a 'thriving' sense as well as in a 'coping' sense. What is important is the realization that a resilient person is not someone who cannot be touched or who is not vulnerable, but a person who knows about his or her own vulnerability and who can in fact be hurt. The term vulnerability is tightly correlated with the term of resilience, for instance through the concept of vulnerability-factors*" (emphasises not included in the original).

A tight link between *vulnerability* and resilience was also highlighted by (Bennett et al. 2014) and was illustrated to be a major issue to be kept in mind when planning e.g. for agriculture. Despite its recognised importance, Gallopín (2006) still questions the overall positive associations correlated with *vulnerability* and furthermore asks whether or not such positive perceptions might also be translated as *internal pertuberation* (Gallopín 2006). However it is argued that vulnerability may lead to an undermining of developments within the agricultural sector. The authors hence stress the importance of maintaining diversity e.g. in agricultural settings in order to impede or complicate undermining tendencies, simultaneously helping to set up more resilient agricultural systems (Bennett et al. 2014).

Two further core aspects of the resilience approach are the knowledge on possible yet constantly occuring surprises (*expect surprise* (Folke 2006; Anderies and Janssen 2013 and Bennett et al. 2014) and feedback loops. Nonetheless surprises or feedback mechanisms may also cause adverse e ects. Looking back on developments in the past, e.g. anthropogenic impact on ecological processes and their interactions, chains of events and interlinkage may be or appear to be quite obvious. However detecting present mechanisms, or predicting outcomes in the future is another matter. This is particularly true in times when is is necessary to draft knowledge based suggestions on how to best interfere today in order to alter projected outcomes in a most bene cial way (e.g. in respect of agricultural approaches linked to climate change scenarios). The Millenium-Ecological-Assessment stated these tasks would seem to be overwhelmingly far out of reach (Millenium Ecosystem Assessment et al. 2005, 226).

Despite this long way Almås and Campbell (2012, 6) point out that resilience would be the most important characteristic for ensuring sustainability in social-ecological systems. While more critical voices like IDS et al. (2012, 8) worry about the resilience approach to replace sustainability *”[...] as the ultimate objective of developme*nt . As stated in the introduction (see Chapter 1.1.1 on sustainability), the sustainability concept has truely become a buzzword. IDS et al. (2012, 8) therefore fear that a similar development would be predetermined for the resilience approach as well. Due to the integrative character of the concept however, various disciplines are brought together, working on shared strategies to enhance resilience and aiming at nding ways on how best to navigate towards a more desirable (yet veiled) future, which is full of surprises. These aspects would thus transfer the resilience concept to a concept ideal for complementing research on sustainability instead of replacing it (Folke 2006).

However expecting uncertainties and surprises also implies the need to include risk assessments and evaluation. Today resilient risk assessments are frequently found in a growing variety of disciplines, including vulnerability research, ecological economics, sustainability sciences or governance (Folke 2006).

Governance has developed to be another focus within the resilience approach. For example, research on top-down command-and-control governance mechanisms was conducted by Ostrom (1990, as cited in Anderies and Janssen 2013) as well as by Holling and Anderies and Janssen (2013), to name but a few.

Nevertheless IDS et al. (2012, 12) criticise that within the framework of the resilience approach operating space within the system and the variance of freedom of people would often be masked. This would further lead to an insu cient apprehension of social dynamics including agency- and power relations. Instead it is argued that the focus would currently lie on the system s potential to recover from disruptions, thereby neglecting potential disturbances through individual choices (even in case of powerful ones) on the means which resilience is shaped by (IDS et al. 2012, 12).

Somehow IDS et al. (2012, 12) seem to deny the resilience approach the ability to account for *internal* disruptions. The authors consequently seem to neglect the characteristics of *adaptability*, described by Walker et al. (2004) (explained further down in this Chapter) as an integrative part of the resilience approach. Furthermore the concept on *dissipative structures* (Gallopín 2006) may explain why a system is structured the way it currently is. This concept believes in constantly occuring, permanent uctuations. In other words non-stop internal- and external disruptions together somehow form a certain kind of balance. This balance is sustained until a threshold is exceeded, leading to a period of more turbulences and large information exchanges, followed by a re-structuring of the system. This re-organised system then nds another balance within di erent thresholds which are adapted to the changed conditions (Gallopín 2006).

Some key characteristics and future pathways related to resilience are collected and listed in the following:

- *Absorbability* describes the strategy of enduring disturbances (Nowotny 2014, 49).

- *Adaptability* is the capacity of an agency to manage internal factors in uencing resilience (Walker et al. 2004) or *adaptive capacity* (Smit and Wandel, 2006, as cited in Folke 2006). These support constant, but dynamic developments (Folke 2006) and are also described as the ability of learning to cope on a longterm basis, and to adjust to a new status quo, in order to increase the short-term capability to cope or respond to new disruptions. High adaptability is stated to result from sustainability, exibility, e ciency, whereas *adjust* and *adapt* need to be distinguished (Gallopín 2006).

- *Transformability* is the ability to build up a system completely from scratch if disruption calls for such a measure (Nowotny 2014, 49 and Walker et al. 2004).
- Nowotny (2014, 50) also quotes characteristics of resilience declared by the Center for Security Studies of the ETH Zurich who also include *robustness* in the sense of withstanding pressure on the system or society (Nowotny 2014, 50 and Anderies et al. (2004, as cited in Folke 2006)) ascribe *robustness* to be used additionally to describe the characteristic of a system, which aims at keeping favourable features, even though slight shifts occur within the environment or even within certain parts of the system itself. Furthermore *robustness* is tightly linked to the capacity of a system to deal with surprise (Anderies and Janssen 2013).
- *Redundancy* on the other hand describes the presence of alternating possibilities of how systems might ful ll their duties e.g. through *creative resourcefulness* or *rapidity* (Nowotny 2014, 50).

Another characteristic of the resilience approach is a constant, critical and thoughtful use of interdisciplinary, shared language. For example the terms *resilience-, vulnerability-* or *adaptive capacity* (Gallopín 2006) are occasionally used as an equivalent and other times with diametrically di ering meanings, because various discipines de ne the terms in di erent ways. Seemingly these concepts vary little from each other and yet, they are de ned slightly di erent. Consequently allowing as much room in the de nitions to cover the exibility required by the individual (highly heterogenous) disciplines using them. This certain amount of exibility may also be explained (to some extent) and rooted in di erences within scienti c traditions of disciplines. However Gallopín (2006) highlights that diversity hence also becomes an obstacle e.g. for a awless communication which is free of misconceptions throughout di erent disciplines and in regard of international, interdisciplinary research. This describes an essential part in interconnecting and bringing together international research disciplines. This formation of a shared communication platform may indeed be considered to be an important precondition for the resilience approach, as partaking research communities need to aim for a constant dialogue, in order to nd shared de nitions which serve as a basis for collaboration. However Walker et al. (2004) point out how a variety of understandings of concepts or de nitions may also create confusion (see also Chapter 1.1 on the problem statement/introduction). On the other hand, without a platform communication would be less likely in the first place and locating and clearifying confusion is an important part of the process in enabeling the finding of solutions (Gallopín 2006).

Connecting disciplines through a shared language is therefore crucial. In addition interrelations between socio- and ecological spheres are necessary in order to enable the view on a whole-system approach. Folke (2006) for instance points out that sometimes coping strategies in one domain (e.g. social capacity) would automatically lead to the assumption of a follow-up managing mechanism in another (e.g. ecology capacity). If in contrast solutions are too specific, they may not sufficiently account for the broader setting. Actions with a too narrow focus would therefore probably lack in the aspired automatic, cascade-like effects of positive outcomes on a larger extent. Focussing excessively on too specific solutions could thus fail to capture the larger setting and consequently fail to sufficiently ignite more far-reaching consequences (Folke 2006).

According to the concept of *dissipitative systems* (see Gallopín 2006), subsequent to an impact, more chaotic periods of heavy perturbations and unexpected consequences would follow. Ultimately though, balance would be found within the altered boundaries with the new thresholds. What is vital to understand however, is that once thresholds are overstepped, returning to a level beyond them again would be costly, improbable or even impossible. Agriculture is considered to be a large driver which would be capable of pushing the boundaries or even (in some regions) exceed thresholds. It is further believed that regional crossings would lead to domino-effects and ultimately cause effects on a global scale. Consequences would then occur internationally, but solutions might still need to be highly heterogenic and specifically tailored to fit the needs for a specific/small region. Moreover it is highly unlikely that there would be one pattern of solution, applicable to any problem all around the world (no *one-fits-all* solution) (Bennett et al. 2014).

Lately the resilience approach seems to get more frequently into focus within the food supply sector (and subsequently so does agriculture) (Kirwan and Maye 2013 and Misselhorn et al. 2012). Unfortunately the task of enhancing resilience in the field surrounding food security, while operating within safe threshold boundaries, is a highly complex and daring task. Moreover current tendencies suggest that accomplishing this task is unlikely (Bennett et al. 2014).

3.2 Outlook

3.2.1 Projections for climate change scenarios concerning the agricultural sector in general

In the introduction it was pointed out that soybean breeding e orts are longterm processes and consequently need to be forsighted and considered. In the same sense signi cant year-genotype interactions were established in further detail in chapter 3.1.2.12.2 (on environmental impacts on soybean breeding targets). Crop cultivation and crop breeding e orts hence need to acknowledge and factor in in uences that are ascribed to climate change and altering environments. Climate is thus considered to be one primary factor in in uencing agricultural production. Consequently this entails agriculture, in contrast to other sectors, being particularly susceptible and vulnerable to climate change (Cajic 2003, 31 and Lal 2013).

But what are current predictions, speci cally for the agricultural production, which are linked to climate change? The Intergovernmental Panel on Climate Change Working Group synthesis Report (IPCC) for instance summarise currently projected risk levels for each of three time frames (the present, near term (2030-40) and long-term (2080-2100)). IPCC also provides levels of con dence with which to expect the described risks in each time frame. For long-term global mean temperature increase for example they provided risk levels for two scenarios: a projection for a 2°C increase and another one for the possibility of a 4°C increase (IPCC et al. 2014, 69f.). They also stress that the number of registered extreme weather events (like droughts, ooding- and re, as well as more frequent frost) are expected to increase. Further projections for future scenarios include increased pest and disease infestation rates, enhanced atmospheric CO_2 levels (as causing factor as well as result) and negative disturbances concerning freshwater endowments (Lal 2013 and Schneider et al. 2011). Above all these weather extremes are very likely to show more drastic amplitudes in severity, possibly leading to considerable yield loss (Allouche 2011).

Besides the availability and the patterns of usage concerning fertilizer and fertile land (e.g. used for agricultural purposes) are also predicted to be a ected by climate change, as all of these resources are expected to be restricted at some point (Deryng et al. 2006; Lal 2013 and Schneider et al. 2011). For instance, these outlooks have already led to a broad discussion on the so-called *water-food-nexus* (Allouche 2011), but IPCC et al. (2014, 69) state that *"[a]ll aspects of food security are potentially affected by climate change, including food production, access, use and price stability (high confidence)"*. They report to expect an increase on global food demand leading to considerable risks in local- and global food security (also classi ed with a high con dence level). It is also stressed that population marked through low income levels (especially in the *Global South*) may be a ected through e ects related to climate change with particular severity, ultimately resulting in follow-up impact on health issues[53].

Issues related to food security are already discussed in more detail in Chapter 3.1.4.2.2. However it seems worth highlighting that well-known and internationally considered reports on climate change emphasise correlations between social- and ecological spheres in their reports with such clearity.

One follow-up conclusion drawn e.g. by IPCC et al., the Millenium Ecosystem Assessment et al. (2005) and Schneider et al. (2011) is therefore the suggestion to stronger focus on food consumption patterns, as their importance will increase.

Consequently it seems unsurprising that discussions on *how* to use available resources and how to improve the use of existing ones are intensifying. Simultaneoulsy debates on adjacent topics are reinforced and include discusions concerning e.g. the use of yields for food, biofuel or non-food purposes; adaptions in cultivation practices to improve agronomic outputs (see Chapter 3.1.4.2.2 on food security); increase e orts to reduce resource inputs (e.g. water or fertilizer) while reduce accompanying risks (like environmental pollution through run-o or leaching); enhance breeding e orts for e.g. yield stability (to improve e.g. the ability of cultivars of enduring extreme weather events without su ering severe yield loss, or adaptions towards higher latitudes to open up possibilities in using elevated land for agricultural purposes (see Chapter 3.1.2.12 on agronomic breeding targets)) (Deryng et al. 2006 and Lal 2013).

In the same way it is stated that growing seasons will need to be used more e ciently (e.g. through shifting sowing dates) and soil health parameters (see Chapter 1.1.2 on soil health) will need to be targeted more thoroughly, in order to improve soil characteristics (like the water holding capacity or improved water storage opportunities in root zones), as well as nding alternative ways of successfully dealing with pests and diseases (Deryng et al. 2006 and Lal 2013).

These lists could of course be extended and should merely give an impression of what kind of topics are currently shi ng into focus and gaining in signi cance. Aspects which are not discussed in the thesis so far, but could be enqueued in the list given above, are

[53] Further (and more detailed) socio-ecological impact, which seem both plausible and probable in the future, are summarised and explained in the Millennium Ecosystem Assessment (see Ecosystems and Human Well-being: Scenarios, Volume 2) (Millenium Ecosystem Assessment et al. 2005).

debates on the utilisation of existing agricultural acreage. Discussions on the topic are generally discussed under the term *spatial heterogeneity* (Kirchner et al. 2015) which refers to a variety of possible region-speci c responses (e.g. to climate change). Besides it may be important to distinctly adress the possibility of a region-speci c positive/bene cial outcome following a disturbance (e.g. climate change) (Lal 2013 and Schneider et al. 2011, see also Chapter 3.1.4.2.8 on resilience).

In general however debates on spatial heterogeneity, as well as land-use choices in agricultural settings, particularly focus on the goal to increase biomass (e.g. through enhanced forage yields). Enhancing biomass may therefore be identi ed as a major target persued in land-use, as providing biomass may be considered as an *ecosystem service (ES)* (Kirchner et al. 2015). Addressing the topic as an ecosystem service would highlight the variety of options in using of the produced biomass. The most frequent types of biomass utilisation (awarding them to be seen as an ES) include a) animal feeding, food and bres for bioenergy uses, b) climate regulation mechanisms (e.g. through soil fertility/ soil health related issues, see Chapters 1.1.2 on soil health and 3.1.2.4 on tillage systems) and c) cultural values and aesthetic aspects (Kirchner et al. 2015).

At the same time this view may require special additional emphasis on possible trade-o s (e.g. bene ts of increased biomass at the expense of loss in biodiversity in vascular plants) (Kirchner et al. 2015). For example it was pointed out by numerous authors (e.g. Cajic 2003, 31; 64; Kirchner et al. 2015 and Schneider et al. 2011) that in a lot of cases intensi cation would mask trade-o s (and synergies). Examples of negative consequences accompanied by e orts of an intensi cation in agricultural production would include an increase in greenhouse gas emissions. Kirchner et al. (2015) therefore suggest to place adaptions in agroecosystems upon multiple fronts such as crop rotation systems, short rotation coppice, conservation tillage and so forth, combined e.g. with a orestation measures. Especially as a orestation would enhance biomass (e.g. for fuel or energy uses), which would have important functions within the ecosystem, while staying out of competition to biomass production intended for food or animal feeding purposes. Consequently Kirchner et al. (2015) suggest to aim at a multitude of measures which play together well (diversity in measures).

Concerning ongoing discussions on the topic (including approaches such as *agroecology*; see Chapter 3.1.4.2.1 on food as cultural heritage), the focus is shifting in an increasing degree towards the question of how to use public goods. Therefore it is important to o er scienti c support to policy makers. (Cajic 2003, 31; 64; Kirchner et al. 2015 and Schneider et al. 2011)

With regard to ES on a regional level, results indicate that there are tendencies towards an increasing intensi cation of agricultural land use. However the degree of such an intensi cation, as well as the e ects, will be quite diverse, depending predominantely on prerequisites of the region. Higher intensi cation rates for example are rather expected in areas with bene cial conditions whereas extensi cation tendecies are projected to be more likely in more peripheral regions (Kirchner et al. 2015).

In addition the decision on *how* to use land and the reasoning *why* it is used in a certain way may o er considerable potential in establishing global environmental feedback mechanisms (positive and negative) e.g. with reference to climate change. Correlations between climate and land-use choices may be particularly detected and illustrated through the use of factors like soil fertility, length of the growing season, fresh water endowments, CO_2-fertilization, pest and disease events, as well as the frequency of extreme climate events (drought, ooding, re, and frost) (Schneider et al. 2011).

Related to this topic various authors (e.g. Allouche 2011; Anderies and Janssen 2013; Lemke 2007, 172 and Sage 2013) emphasise the importance of *key drivers* (e.g. global commodity trade- and subsidy systems, policy maker s decisions on environmental policies) for resource management strategies as well as in respect of food security issues and land-use decisions. In the same way Kirchner et al. (2015) for example stress the importance of recognising the in uencial power of national policy (perceived as in uential *factor).* They used e.g integrated modelling frameworks (IMF)[54] to capture interlinkage between climate change, human systems and their environments. Moreover they used data from various disciplines such as soil science, climatology, agronomy economics and animal husbandry to support illustrating at least some impact chains in this complex topic. In four climate change scenarios, which they have run, results showed national policy to outrun most other in uential factors with the exception of regions as well sectors that showed high vulnerability towards climate change (2025-2040) in the rst place.

[54]The integrated modelling frameworks (IMF) approach as well as other models used to establish climate scenarios aim at illustrating plausible models of future developments. This is acieved by describing responses and creating climate projections which are coherent with current predictions on future developments. Outlooks often include factors such as greenhouse gas emissions, possible influences through anthropogenic actions and other influential factors that are currently known. Therefore different scenarios are based on a certain set of assumptions (such as land-use change, energy use, greenhouse gas emissions, ...) resulting in uncertainties that go along with these assumptions. Various scenarios may therefore serve as illustration of the sensitivity and vulnerability of a certain unit (e.g. region/nation/...) to climate change (Cajic 2003, 31; 64).

3.2.2 An example of four climate change simulation scenarios for the Austrian agriculture

Schneider et al. (2011) ran four di erent simulation scenarios[55] and included two deforestation scenarios to investigate on in uences on external drivers (e.g. population growth, GDP, lack of su cient land, limited water resources and technical innovations) and their e ects on regional food production on per capita food supply. Additionally they enquired into e ects of external drivers on the proportion between meat and animal products compared to vegetables and plant products with respect to food production patterns. Results from the international, partial equilibrium model on the agricultural and the forest sector revealed that per capita food levels were enhanced in all four scenarios. However in these four scenarios food prices were hardly a ected, despite the experience of research on food consumption characteristics generally being rather illuminative and o ering valuable insights into matters related to food prices (e.g. as potential feedback mechanisms in issues related to food security) (Schneider et al. 2011, see also Chapter 3.1.4.2.2 on food security).

Schneider et al. (2011) point out signi cant correlations between food demand characteristics and their implication on land-use characteristics and distribution patterns. On a global scale, for example, it was suggested that the need for agricultural acreage would enhance up to 14% between the years 2010 to 2030. Furthermore the results revealed how regulations on deforestation had a notable impact on land pricing and on water resources which, however, was hardly re ected in the level of global food production or in food prices. With respect to food consumption levels the highest partial in uence on per capita derived from a change in income. In contrast the most signi cant enhancement in total food production was linked to population growth.

Results further suggested that relieve through technical innovations in the agricultural sector may be strongly in uenced by a decreas in food commodity prices and enhancements in factor prices. However changing costs, e.g. due to higher yields, may a ect land- and water resources in a higher magnitude than food prices. The reasons are thought to derive from costs linked to technical innovations which consequently veil food prices (Schneider et al. 2011).

Besides, mere intensi cation is reported to create a backloop which would ultimately

[55] Further details on the study may be investigated in the paper [Schneider, Uwe A. and Havlík, Petr and Schmid, Erwin and Valin, Hugo and Mosinier, Aline and Obsteiner, Michael and Böttcher, Hannes and Skalský, Rastislav and Balkovič, Juraj and Sauer, Timm and Fritz, Steffen, *Impacts of population growth, economic development, and technical change on global food production and consumption*, Agricultural systems (2011), 204-215.].

result in degradation. This would further explain why (Schneider et al. 2011) food production/pricing and consumption levels were relatively stable over all four scenarios (run for a time period until 2030). However a reduction in per capita consumption was barely detected, as it did not exceed 5%.

These results provided evidence that the required increase in food quantity would originate either in population growth or increase of income. However the latter scenario would have to be accompanied by scarcening resources, in order to lead to enhanced prices for foodstu as well as for factor prices that are required for its production (Schneider et al. 2011).

Relief through technical innovations in the agricultural sector was strongly in uenced by a decrease in food commodity prices and increased factor prices (see also Chapter 3.1.4.2.2 on food security).

In summary in all four scenarios, the largest impact on per capita food consumption patterns originated in changes of the per capita income. Simultaniously the results revealed that population growth without an accompanying shift in income or technical change lead to the severest decline in per capita food consumption (Schneider et al. 2011).

> *"Climate change as a driving force likely puts further pressure on ES [ecosystem services] supply in agricultural landscapes (Schröter et al., 2005). This can happen directly as an impact on ecosystem functions and processes that provide ES (e.g. sediment loss, see Mitter et al., 2014) and indirectly through autonomous adaptation strategies by farmers (Briner et al., 2012; Leclère et al., 2013; Schönhart et al., 2014). The impacts of these two driving forces will strongly depend on regional and local socio-economic, and biophysical characteristics like farmers' responses, resource endowments, and soil conditions, thereby making it paramount to account for spatial heterogeneity (Bateman et al., 2013)* (Kirchner et al. 2015).

This statement further stresses the need of transdisciplinary approaches that link the ecological- and the social spheres, putting increasing emphasis on the understanding of desicion-making processes and maintaining diversity.

3.2.3 An example of a *circulation modelling* approach concerning climate change scenarios in Austrian soybean production

In her PhD-thesis Cajic (2003, 118) applied a general circulation model with the so-called CROPGRO model in which ve di erent climate change scenarios were run for two cultivars in Gro Enzersdorf, Lower Austria. Results of all scenarios revealed tendencies towards shortening growing periods of soybeans in the future. This trend was related to higher periodical temperatures in all simulation scenarios which lead to faster emergence, faster development, earlier owering, earlier maturity and nally resulted in shorter overall growing periods.

In scenarios where temperature and precipitation rates were enhanced, yields in Marchfeld were expected to increase 25% until the year 2080 (output data given by the CSIRO-Mk2b model). Such tendencies with signi cant yield increase were even more obvious in simulations in which projections on atmospheric CO_2 levels were included (Cajic 2003, 118).

Cajic (2003, 118f.) provides a list of adaptations which are thought to optimise soybean cultivation in the setting of Gro Enzersdorf with particular respect to currently predicted requirements in soybean cultivation under changing environmental conditions. She initially suggests earlier planting dates and cultivars belonging to earlier maturity groups (MG 000, 00 and 0), because earlier planting dates would reduce the likelihood of increased exposure to heat events and water stress, resulting in reduced risk of crop damage or yield loss. In the same sense she points out that early sowing dates in soybean cultivation are reported to be linked to enhanced yields and improved seed quality (Cajic 2003, 118f.). However it needs to be stressed that such outcomes may only be expected on the precondition of favourable growing environments. This includes a lack of droughts, fusariosis/*Rhizoctonia* or *Diaphorthe sp.*, as well as a lack of late frost events or delayed emergence. Very late sowing dates, in contrast, bear the risk of un nished ripening and grain lling stages, leading to major yield loss (see also Chapter 3.1.2.1 on planting dates) (De Bruin and Pedersen 2008; Singh G. et al. 2010, 144f. and Soldati 1999, 678).

In regard to low precipitation rates reported at the experimental site, Cajic (2003, 118f.) also points out the importance of improved moisture conservation. It is her opinion that conservation tillage systems and mulching techniques could serve as suitable options (more on the subjects see Chapters 3.1.2.4 on tillage systems and 3.1.2.8.3 on weed prevention management strategies).

Thus, Cajic (2003, 118f., 120) emphasises possible requirements in adapting current fertilizer- and irrigation techniques and points out that breeding e orts, selection, as well as biotechnological innovations are believed to o er further possibilities in reducing pressure on crop cultivation which is deriving from increasing drought events, water, pests and diseases. She also stresses the need to continue e orts placed into optimising soybean management practices (see Chapters 3.1.3.2 on consumption related breeding targets and

3.1.2 on crop production strategies).

However, in her master s thesis Seifried (2014, 94f.) reports that climate change may lead to a shift within the core production areas of soybeans, as current predictions would forecast an extension of the soybean acreage into regions farther north. This would ultimately entail chillier environments while the general mean temperatures would simultaneously increase. Consequently future conditions for enhanced Austrian soybean production are projected to be favourable. Seifried thus states that soybean may eventually replace other crops in an increasing amount (intensifying competition over existing acreage between di erent crops).

4 DISCUSSION AND CONCLUSION

The initial research questions aimed at elaborating on and enquiring possibilities of *sustainable* soybean breeding targets in Austria in 2050. But soon after seeking further information on the concept of sustainability it became apparent that it is rather difficult to work with due to its holistic and constantly evolving characteristics (see also Moldan et al. 2012; Popp et al. 2000 and Singh R. R. et al. 2009). For the thesis this would have resulted in *the* major task resting upon the responsibility of carefully selecting meaningful and suitable indicators. However this approach would have entailed the risk of getting lost in vast amounts of possible indicators. To me this approach felt limiting and its possibilities in offering freedom to explore adjacent topics probably would have been restricted. The means would hence have turned to an end. Therefore, the initial research question was slightly adapted and the aim of this thesis then was to identify long-term soybean breeding targets (agronomic and consumption related) in Austria until 2050, coherent with the concept of *sustainability* and aligned with current discussions on e.g. enhancing *soil health*, global food systems and *food security*.

However difficulties mentioned in connection with the sustainability concept were able to be overcome when additionally introducing the resilience approach. The resilience approach was particularly highlighted and valued in various disciplines as a vital approach e.g. in complementing the sustainability concept and acting most beneficial in promoting transdisciplinary research for example by providing suitable frameworks for communication and collaboration.

With regards to agronomic breeding goals the results suggest the necessity for enhanced breeding efforts in developing more *robust* soybean cultivars. This circumstance is particularly rooted in predictions on more frequently occuring extreme climate events that are furthermore expected to show more severe amplitudes. Consequently it is suggested to place strong emphasis on enhancing yield stability, while simultaneously a) educating benefits on enhancing this trait even if it comes at the cost of reduced yields and b) strategies in diversifying crop cultivars in order to spread the risk of yield loss due to significant year-environment interactions and c) risk evaluations and the development of risk management strategies.

Moreover climate change very likely leads to enhanced weed infestation rates, accompanied by invasive weeds and pests and combined with a decreasing spectrum of accredited herbicides. It is therefore suggested to place enhanced focus on understanding weed population developments under climate change, to increase efforts in non-herbicide weed management strategies and intensify research with particular focus on mixed cropping and intercropping techniques as strategies and knowledge on the subject are still in their infancy.

All of these suggestions should of course be accompanied by smart crop management practices that are defined by good practice standards, (e.g. using beneficial crop rotations in order to support soil health, healthy crop stands and healthy crop environments).

In respect of breeding goals related to (human and animal) consumption patterns, shifts in diets and consumption patterns related to food security issues are projected. As changes in perceived cultural values of food usually take a long time, it is strongly advised to target an increase of the visibility of soybean as valuable and beneficial food for human consumption. Consumers should be given opportunities to make educated desicions. Simultaniously it is believed that a suitable framework needs to be created in order to allow for (further) development of the cultural value of soybean while at the same time intensifying research in alternative supplements for soybean in animal feeding materials. This is thought to be crucial, because animal feeding industries are now specialised in processing soybeans. Shifts to alternative feeding supplements would therefore need time, money and, probably of even more importance, convincing arguments for their customers. Additionally such complementary developments would be cruicial to avoid bottlenecks (especially for organic farming) with respect to the supply and to defuse competitiveness between soybean yield intended for human consumption and animal feeding purposes.

Furthermore it was illustrated how policy is a key influence factor in respect of land-use patterns. Consequently it is suggested to aim at a patronage of a soybean strategy not only coherent with the EU protein strategy, but also tailored to specific (regional) requirements in Austria. However, policy makers also have to face the task of dealing with trade-offs (cf. Millenium Ecosystem Assessment et al. (2005, 433)). Therefore continuous dialogue with various stakeholders is one prerequisite for enabeling knowledge-based, appropriate decicions and implementing a multitude of well-coordinated measures, which are advisably geared towards a *resilient* agriculture.

Conclusion summarised in bullet points:

- aim at diversity (in crops and weeds alike)
- aim at robust cultivars (improved tolerance towards extreme weather events) accompanied by risk evaluations/risk management strategies (yield loss) as well as re-establishing yield stability as a primary goal (even if correlated with lowered magnitudes in seed yield levels)

Figure 24: Field trial with di erent cultivars of the *Landwirtschaftskammer Oberösterreich* in Upper Austria, 2014

- aim at tight collaboration with policy makers
- apply the resilience approach (combined with the sustainability concept)
- enhance food safety issues and seed quality characteristics with a simultanious increase in the visibility/cultural value of soybeans intended for human consumption as well as nding subsidies/alternative products developed for animal feeding (e.g. to avoid bottlenecks for organic farming)
- improve non-chemical weed control, stronger focus on weed s response to climate change
- land-use changes: focus on the understanding on desicion making processes (also in relation to consumer behaviour) and in uential factors
- promote soil health and cultivation management practices that enhance healthy crop stands (e.g. smart crop rotations, incl. tendencies towards shorter growing periods of crops)
- promote transdisciplinary research (*common language* as prerequisite to establish/support dialogue and collaboration) and recognise the need and urgency for transdisciplinary approaches

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APPENDIX

Curriculum Vitae

Education:

since 2012	Master program Applied Plant Sciences at the University of Natural Resources and Life Sciences, Vienna
2007-2012	Bachelor program Agricultural Sciences at the University of Natural Resources and Life Sciences, Vienna
2005-2010	Diploma program International Development, University of Vienna
1998-2005	High school Kirchdorf/Krems

Selected work experience:

October - November 2015	Internship at Arche Noah, Association for Preserving and Developing the Diversity of Cultivated Plants, Langenlois, Lower Austria
August 2014 - January 2015	Project related work concerning soybean cultivation, Chamber of Agriculture Upper Austria, Linz, Upper Austria
August 2013	Internship at the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Department Genebank, Gatersleben, Sachsen-Anhalt, Germany
March - April 2010	Research stay in Nicaragua
August 2009	Climate Alliance Upper Austria, Linz, Upper Austria
March - May 2008	Technical employee at the University of Natural Resources and Life Sciences, Department of Crop Sciences, Division Plant Breeding, Vienna
November 2008 - January 2009	Technical employee at the University of Natural Resources and Life Sciences, Department of Crop Sciences, Division Plant Breeding, Vienna

Language skills:

German (mother tongue), English (fluent), French (good knowledge), Spanish (basic knowledge)

Developmental stages by Fehr and Calviness (1977, as cited in Cajic 2003, 29f. and De Costa and Shanmugathasan 2002) devides the growing stages of soybean plants into vegetative (V) and reproductive (R) stages. Starting with emergence, unifoliate (node of the 1st leaves), and trifoliate nodes (nodes of the 2nd leaf to the last leaf on the main stem), owering (R1), full bloom (R2), beginning pod (R3), full pod (R4), beginning seed (R5), full seed (R6), and physiological maturity (R7), full maturity (R8) (Fehr and Caviness 1977).

Stage code	abbrevated stage code	Description
Vegetative stages:		
VE	Emregence	Cotyledons above the soil surface.
VC	Cotyledon	Unifoliate leaves unrolled sufficiently so the leaf edges are not touching.
V1	First-node	Fully developed leaves at unifoliate nodes.
V2	Second-node	Fully developed trifoliate leavesat at node above the unifoliate nodes.
V3	Third-node	Three nodes on the main stem with fully developed leaves beginning with the unifoliate nodes.
V(n)	nth-node	n number of nodes on the main stem with fully developed leaves beginning with the unifoliate nodes, n can be any number beginning with 1 for V1, first-node stage.
Reproduc-tive stages:		
R1	Beginning bloom	One open flower at any node on the main stem.
R2	Full-bloom	Open flower at one of the two uppermost nodes on the main stem with a fully developed leaf.
R3	Beginning pod	Pod 5 mm long at one of the four uppermost nodes on the main stem with a fully developed leaf.
R4	Full pod	Pod 2 cm long at one of the four uppermost nodes on the main stem with a fully developed leaf.
R5	Beginning seed	Seed 3 mm long in a pod at one of the four uppermost nodes on the main stem with a fully developed leaf.
R6	Full seed	Pod containinga green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf.
R7	Beginning maturity	One normal pod on the main stem that has reached its mature pod colour.
R8	Full maturity	95% of the pods have reached their mature pod colour. Five to ten days of drying weather are required after R8 before seeds have less than 15% moisture.

Table 21: Developmental stages of soybean

Source: Fehr and Calviness 1977 (as cited in Cajic 2003, 30 and De Costa and Shanmugathasan 2002). Note that this is not the otherwise often used BBCH scala.