7 Developing Soy Production in Central and Northern Europe

Fredrik Fogelberg[1]* and Jürgen Recknagel[2]

[1]RISE – Research Institutes of Sweden, Uppsala, Sweden; [2]Center for Agricultural Technology Augustenberg, Emmendingen, Germany

Abstract

The soybean is an important ingredient of livestock feed in Europe and is also widely used in foods. Most soy used in Europe is imported (about 97% as beans and meal), mainly from South America and the USA. European soy production is currently concentrated in the south (Italy) and south-east (Balkan countries). Based on research conducted in Sweden and Germany, this chapter provides pointers to the development of the soy crop in central and northern Europe. It provides an overview of the history of the development of the crop in northern Europe, outlines relevant recent field research, and discusses aspects of good production practice. We focus on new production areas, generally north of traditional production areas. In recent years, interest in growing soybeans has spread east and north from Romania and Italy and parts of France to Austria, Germany, Hungary, Slovakia, the Czech Republic, Poland and even the BeNeLux countries, the Baltic and Scandinavian countries, with subsequently rising acreages. In order to succeed with soybean cropping in central and northern Europe, cultivars of the 00, 000 or 0000 maturity groups should be used. Grain yield in Scandinavia is about 2 t/ha. Crops in Germany and Austria produce about 2.5–3.5 t/ha. Knowledge about locally adapted cultivars and production technology is needed to support the development of the crop in new production regions. To ensure profitability of this new cropping, infrastructure for processing to feed and food has also to be developed.

The Biology of Soy

Soybean (*Glycine max* (L.) Merr.) is familiar mainly as imported soybean meal used to fill Europe's plant protein deficit. The soybean is an annual plant ranging in height from about 35 cm to 130 cm. The flowers are small, typically 3–8 mm, white or purple in colour, and initiated in the leaf axil on the stem, often from the fifth node and higher. The pods are slightly curved, about 4–6 cm long, covered

*Fredrik.Fogelberg@ri.se

with small brown or grey hairs. During maturation the pods turn brown and the plant drops its leaves. By harvest time, the stem remains with dry, firm pods.

Soy is a short-day plant, which means that the initiation of flowering is dependent on a minimum and lengthening night period. As the days grow shorter after the summer solstice, soybean enters its reproductive phase with the sensitivity to shorter days dependent on genetic factors. After flowering, the number of days to maturity depends on temperature. The heat required to bring soy to maturity is expressed either in crop heat units (CHU) or growing degree days. These two figures are temperature sums derived from two slightly different development models. The CHU method uses a linear relationship for night-time development (with a 4.4°C base temperature for night) combined with a non-linear relationship for day-time development using a base temperature of 10°C and an optimum of 30°C, above which the rate of development declines with further temperature increases. In German field research, the heat sums are calculated using the Canadian heat sum system (Brown and Bootsma, 1993) which is based on the daily maximum and minimum temperature during the life of the crop and calculates a mean of day- and night-time temperatures separately as follows:

$$CHU = (CHU_{day} + CHU_{night})/2$$

in which

$$CHU_{day} = 3.33(T_{max}-10) - 0.084(T_{max}-10)^2 \text{ and } CHU_{night} = 1.8(T_{min}-4.4)$$

Soy cultivars are divided into 14 maturity groups from 0000 (earliest) to X (latest). The cultivars in the 000 and 0000 groups (triple and quadruple zero) are adapted to longer days found at higher latitudes.

About 4.5 million ha of soy were grown in Europe including Russia in 2014, yielding 9 million t which is an average yield of 2 t/ha. In the European Union (EU) about 0.6 million ha were grown yielding 1.85 million t which is an average yield of 3.2 t/ha (Table 7.1). Yields were high in central Europe in 2014 because of good weather conditions. It compares with an average of 2.9 t/ha in Brazil, 3.2 t/ha in the USA and 2.8 t/ha in Argentina, which are the main exporting countries (FAOSTAT, 2016). Based on data for 2005–2013 provided by FAOSTAT, Saatzucht Donau (2015) report that over years the relationship between soybean and grain maize yields in Austria remains relatively consistent at 27:100 on average, varying only between 26:100 and 29:100. This indicates that yield variability in well-adapted cultivars is not greater than in other crops. European efforts to reduce the European protein deficit could include increasing soy production in central and northern Europe (i.e. Europe north of the Alps), alongside other supply-side measures such as expanding faba bean production. The demand for genetically modified (GM)-free plant protein further increases the opportunities for European-grown soy.

Status of Soybean Cropping Development

The soy research community in northern Europe is small. Current research addresses issues such as cropping systems, suitable cultivars and the processing of

Table 7.1. Area and yield of soy in the 18 main production countries in Europe 2014. (From Copa Cogeca, 2015; FAOSTAT, 2016; and estimates from the German Soy Association.)

Country	Area (ha)	Yield (t/ha)	Production (t)
Ukraine	1,792,900	2.2	3,881,930
Russia	1,915,895	1.4	2,596,635
Italy	232,867	4.0	933,140
Serbia	154,249	3.5	545,898
France	75,800	3.0	227,262
Romania	79,275	2.6	202,892
Croatia	47,104	2.8	131,424
Austria	43,800	2.7	118,100
Hungary	42,980	2.7	115,600
Republic of Moldova	52,800	2.1	109,300
Slovakia	33,227	2.5	83,905
Germany[a]	10,000	2.4	24,000
Greece[b]	7,500	2.8	20,900
Poland[b]	14,100	1.3	18,300
Czech Republic	7,242	2.3	16,493
Bosnia and Herzegovina	4,186	2.2	9,020
Switzerland	1,496	2.6	3,882
Spain	800	3.4	2,700

[a]Estimates from the German Soy Association based on data from several German Länder.
[b]From Copa Cogeca (2015).

soybeans for food and feed. In Sweden, research is maintained at the Research Institutes of Sweden, Uppsala (RISE) and partners at the Scandinavian Seed AB. There are ongoing field trials at the Åland Experimental Station in the Åland Islands of Finland. Farmers in southern Finland have experimented with soybean cropping since 2011. The Estonian Crop Research Institute in Jõgeva is active in breeding, but the area is still limited to less than 100 ha. There is also research on soybean in the Lithuanian Research Centre for Agriculture and Forestry in Babtai and at Pure Horticultural Research Centre.

In Germany, the University of Hohenheim has worked on soy since the 1970s. Supported by a national project to extend soybean cultivation in Germany, FiBL Deutschland e.V., Forschungsinstitut für biologischen Landbau (Research Institute of Organic Agriculture) in Frankfurt am Main, together with the Deutscher Sojaförderring (German soy information ring) at LTZ Augustenberg, have intensified the existing long-term experiments in five German states by coordinating tests of more than 50 cultivars on 33 sites all over Germany during the years 2011–2013. Additional tests for cold tolerance have been carried out at Julius Kühn-Institut (JKI), Bundesforschungsinstitut für Kulturpflanzen (Federal Research Centre for Cultivated Plants) in the Rostock area. The University of Kassel and Hochschule Osnabrück have worked on cultivation systems for cooler regions and the Landessaatzuchtanstalt (State Plant Breeding Institute) of Baden-Württemberg started a breeding programme for 000-tofu-beans. Details of the German research activities are provided by the Deutscher Soja-Förderring (2015).

Since 2013 the production area evolved from 7500 to 10,000 ha in 2014 and 17,600 ha in 2015.

Institut National de la Recherche Agronomique (INRA) has conducted a significant amount of research in France. While work on innoculation continues, INRA research on breeding has ceased but Terres Inovia and two private breeders continue work on soybeans in France. The production area declined from 134,000 ha in 1989 to 26,000 ha in 2008 but has recovered to 43,000 ha in 2013, 74,700 ha in 2014 and 122,000 in 2015. Recent increases have occurred in northern France. Breeding started recently in the Netherlands and two cultivars were listed in 2013. The production area was 30 ha in 2013 and 110 ha in 2014. In Poland, breeding started in 1974 and some cultivars were listed in 1994 and 2002. The production area is growing rapidly and reached 17,900 ha in 2013 and 14,100 ha in 2014. In the Czech Republic, the area reached 6500 ha in 2013, and 7200 ha in 2014, while Slovakia cultivated about 29,000 ha in 2013 and 33,000 ha in 2014. In Austria and Hungary the cultivation area in 2013 was about 42,000 ha each and about 1000 ha more in 2014 (FAOSTAT, 2016).

The Russian Vavilov Institute in St Petersburg has a collection of about 7000 soybean accessions of which it is estimated that 1238 can be classified as very early and suitable for the non-chernozem zone of Russia. Unfortunately, budget constraints prevent the institute from doing any major development work on soy. In Belarus, breeding of 00 cultivars is conducted by the Soya-North Co. in Minsk, but the extent of these activities is unclear. A more substantial effort on breeding exists in Ukraine.

History of Soy Development in Europe

Although the soybean has been cultivated for thousands of years, the first record of it in Europe is as late as the 1700s. It was mentioned by Kaempfer (1712) who was a German scientist who had lived for some years in Japan. The plant was later cultivated mainly in botanic gardens and not used for food or feed. The first record of soy cultivation is from Linné relating to a garden in the Netherlands in 1737 (Shurtleff and Aoyagi, 2007). More than a century later, an Austrian agronomist, Friedrich Haberlandt, promoted the use of soy after having received some seeds from the Japanese and Chinese delegations at the Vienna world fair in 1873. He organized a large study on the viability of soybeans with 160 sites in 1877 in almost all German-speaking countries, including all parts of the Habsburg Empire. He published the results in *Die Sojabohne* (Haberlandt, 1878). After his sudden death later in 1878, work on soybeans in Austria was almost abandoned.

In 1908, a shortage of cotton seed vegetable oil resulted in imports of soybeans from Japan via the USA. The soy oil was popular and this triggered cropping in central Europe from where it later spread throughout Italy, France, Russia and Germany. In Germany, interest in soy grew after World War I and this was followed by efforts to boost German production in the 1930s and during World War II. Four soybean cultivars were listed in Germany and cultivation was mandatory in relevant regions at that time (Drews, 2004). After World War II, soybean breeding in Germany continued at a low level and some cultivars that were less sensitive to day length were identified. Breeding continued in western Germany at the

University of Giessen and in East Germany (GDR) at Gatersleben and Dornburg. Some of the cultivars from Dornburg were quite successful and were sold to Saatbau Linz in Austria after the re-unification of Germany in 1990. In Austria, Johann Vollmann has worked on specific questions of soybean breeding at BOKU in Vienna since 1990. Saatbau Linz started soybean selection at the Reichersberg station in 1990 but stopped it in 1995–96 after a significant reduction in production area from 54,000 ha in 1993 down to around 13,000 ha from 1995 onwards, following the accession of Austria to the EU in 1995. In 2000 Saatbau Linz cooperated with Probstdorfer Saatzucht to create a common breeding company named 'Saatzucht Donau'. Soybean breeding in Austria started again in 2006 at Reichersberg and has been intensified since 2011 (Saatzucht Donau, 2015). In Switzerland soybean breeding started 1981 at Changins station, now part of Agroscope, and has produced several cultivars of interest for central Europe (e.g. 'Gallec', 'Opaline', 'Amandine').

In the UK, pioneering work was done as early as 1913 by J.L. North, curator of the Royal Botanic Society of London, in adapting soybeans to English conditions. By 1923, using early cultivars introduced from various sources, North selected two or three strains that matured fully and gave good yields under English conditions. North eventually surmounted great difficulties and in 1933–34 was able to raise England's first successful crop of soybeans at the Fordson Estates. Good crops were then produced each year up to 1936. With some help from William Morse of the United States Department of Agriculture (USDA), North acclimatized four early-maturing cultivars that gave good yields.

In 1968 Ray Whisker began experimenting with growing soybeans (especially large-seeded vegetable-type soybeans) in his garden near London. He soon built up the largest British seed collection in private hands. In 1969 he began growing cultivar 'Fiskeby V' from Sweden with good results, and by the 1970s this vegetable-type soybean was available from Thompson & Morgan for gardeners. By 1975, Whisker had evaluated more than 200 cultivars from 18 countries (Shurtleff and Aoyagi, 2007). Modern British crop development started again in 1998 with 0000 cultivars in the early 2000s and reached about 3000 ha. This declined to 150 ha in 2013.

Sven Holmberg of company Algot Holmberg & Söner, Fiskeby, Norrköping in Sweden was a pioneer in the breeding of early maturing cultivars (Holmberg, 1947). He made crosses based on cultivars from Japan, Canada and China in the late 1940s and introduced a series of cultivars called 'Fiskeby I' to 'V'. The last cultivar, 'Fiskeby V', was introduced in Sweden in 1968 and is still considered as one of the earliest and highest yielding soybeans for northern European conditions and is still used in breeding, including in Canada. Unfortunately, the company archive is lost and we have only fragments of original data left from field testing and the breeding cultivars used.

The Canadian government started a breeding programme in the 1980s for conditions as far north as Québec and Manitoba. This research resulted in special-purpose cultivars for Asian food markets. From the late 1980s on, these cultivars were also quite successful in Austria, the Czech Republic and Germany where a producer of organic tofu organized the first inclusion of three Canadian soybean cultivars in the German National List in 2005 ('Alma Ata', 'Lotus' and 'Primus'). Canadian cultivars were the basis for the development of soy cultivation in Bavaria (e.g. 'Merlin 000' and 'Gentleman 0000') as well as in the upper Rhine valley (e.g. 'Ohgata 00' and 'Primus 00'). Switzerland is another source of new cultivars with a breeding programme at Agroscope. Companies in France breed not only for the southern areas (0, I cultivars) but also for the central and northern parts of the country with 00 and 000 cultivars.

The development of soy in Europe therefore has the benefit of quite an active breeding community and trade infrastructure, considering the size of the crop and its early stage of development. Saatbau Linz and Probstdorfer Saatzucht with Saatzucht Donau, Saatzucht Gleisdorf and RWA in Austria, ZIA in the Czech Republic, Delley Samen und Pflanzen AG in Switzerland (promoting the cultivars of Agroscope ACW), Euralis and RAGT from France and Pflanzenzucht Oberlimpurg (PZO) from Germany are examples of seed companies providing suitable cultivars.

Future Potential for Soy in Central and Northern Europe

In the 1940s, Scandinavian breeders used cultivars from Japan and Manchuria to breed for day-length neutrality, contributing to the foundation of northern European soy production. Today, the majority of cultivars on the market worldwide are too sensitive to day length and do not flower in northern Europe. The use of the maturity groups gives a general idea of the suitability of cultivars for a region. From our practical experience, we regard central and northern Europe as two potential production regions within each of which the combined response to day length and temperature are similar.

1. North of the Alps and the French Loire river and south of a line from Amsterdam to Berlin and Warsaw, including the northern half of France, southern BeNeLux countries, Switzerland and Austria (north of the Alps); southern and central Germany; the Czech Republic, Slovakia and southern Poland.
2. Further north to the North Sea and Baltic Sea: northern Netherlands, north of the Amsterdam–Berlin–Warsaw line, including the Baltic countries, Finnish Åland Islands, southern Sweden with Gotland, and Denmark.

Cultivars identified as 00 may perform well in a 000 region. Likewise, some 000 cultivars have been shown not to be suitable for Scandinavian conditions. Thus, regional field testing is required.

Suitability of cultivars

Advances in plant breeding are crucial to adapting soy for European conditions. In agreement with Canadian research, Mechtler and Hendler (2010) report the results of cultivar trials in Austria showing that breeding resulted in 1.6% and 1.2% yield increase per year for 000 and 00 cultivars, respectively, registered between 1990 and 2010. The yield potential increased from 2.8 t/ha to 3.9 t/ha for the 000 group and from 3.0 t/ha to 4.2 t/ha for the 00 group. Protein yield increased with grain yield and the individual seed weight also increased.

Table 7.2 shows that in any one region there may be a choice of suitable cultivars from across Europe, for example those bred in Austria and Switzerland can be high yielding in Sweden. This means that provided day-length neutrality and earliness of maturity requirements are met, cultivars selected in one region may be suited over a larger area. Therefore, the classification of cultivars according to maturity groups is only a guide. The descriptive list of cultivars from Austria (Ages, 2016) proposes a points scheme to give a finer maturity differentiation between cultivars with 1 for 0000 cultivars, points 2–4 for 000 cultivars, points 5–7 for 00 cultivars and 8 for 0 cultivars.

Site effects

Despite the wide adaptation of soy, there may be substantial site effects within regions, which means that local cultivar testing is particularly important

Table 7.2. Grain yield (at 14% moisture content) of early maturing soybean cultivars evaluated in the St Petersburg region 2003–2008 (adapted from Vishnyakova and Seferova, 2013) and of cultivars tested in southern Sweden in 2012 (adapted from Fogelberg, 2013).

St Petersburg region			Southern Sweden[a]		
Cultivar	Origin or grown in	Yield (t/ha)	Cultivar	Origin or grown in	Yield (t/ha)
‘Fiskeby 1040-4-2’	Sweden	2.7	‘Annushka’	Ukraine	1.3
‘Mageva’	Russia, Ryazan	2.5	‘Moravians’	Canada/Czech Republic	1.4
‘Fiskeby 840-7-3’	Sweden	2.5	‘Bohemians’	Canada /Czech Republic	1.5
‘PEP 28’	Russia, St Petersburg	2.3	‘Silesia’	Canada /Czech Republic	1.4
‘Svetlaya’	Russia, Ryazan	2.3	‘Brunensis’	Canada /Czech Republic	1.7
‘PEP 27’	Russia, St Petersburg	2.2	‘Sultana’	France/ Germany	1.6
‘SibNIIK 15/83’	Russia, Novosibirsk	2.1	‘Klaxon’	France	1.7
‘Altom’	Russia, Altay	1.8	‘Merlin’	Canada/ Austria, Germany	2.0
‘Stepnaya 85’	Russia, Kemrovo	1.8	‘Lissabon’	Canada/ Austria, Germany	1.7
‘KG 20’	Canada	1.6	‘Capnor’	France/Austria	1.5
‘SOER 4’	Russia, Saratov	1.4	‘Gallec’	Switzerland/ Austria	2.0
‘USHI 6’	Russia, Ulyanovsk	1.3	‘Paradis’	Switzerland	1.8

[a]The 2012 season in Sweden was characterized by low temperatures and high rainfall.

for the development of the crop. Table 7.3 provides grain and protein yield data (mean of 3 years) for a range of well-adapted cultivars at three sites in Germany. Depending on site quality and cultivar, yields in Germany vary between 2.5 t/ha and 4.8 t/ha, protein contents vary from 37% to 43% and protein yields from 0.9 t/ha to 1.7 t/ha. Harvesting dates are influenced not only by the heat sums but also by weather conditions after physiological maturity of the crop.

Swedish field experiments have shown that yields of early cultivars can reach about 2.5 t/ha in that country. However, a cool and wet spring in combination with low summer temperatures may lower the yields considerably. In 2012, 14 cultivars were tested in southern Sweden. Those that earlier had proven to give high yield, such as the Czech (Canadian) cultivar ‘Silesia’, were low yielding due to the unusual cold and rainy summer while Austrian (Canadian) and Swiss cultivars such as ‘Merlin’ and ‘Gallec’ were still able to give acceptable yields (Table 7.2). Similar results were obtained in northern Germany (Rostock and Wolfsburg) and in northern Bavaria (Schweinfurt) while ‘Merlin’ and ‘Gallec’ yielded 3 t/ha and 3.3 t/ha, respectively, on a fertile loess near Kassel in central Germany. The results show that water supply during generative development as determined by soil texture is an important factor determining yield.

Table 7.3. Yield (at 14% moisture content) and protein yield, lodging and date of maturity of early matured soybean cultivars evaluated at three sites in Germany in 2011, 2012 and 2013. The average heat sums (crop heat units, CHU) accumulated by the crop and the annual rainfall (mm) as well as the Müncheberg soil quality rating (SQR)[a] are provided for each site.

	Beetzendorf (Altmark, Wolfsburg (2717°CHU, 575 mm precipitation, SQR 45) (northern Germany)		Salbitz (Dresden-Leipzig) (2965°CHU, 600 mm precipitation, SQR 86) (eastern Germany)		Cologne-Auweiler (2941°CHU, 750 mm precipitation, SQR 75) (western Germany)	
Cultivar	Yield (t/ha)	Protein yield (t/ha)	Yield (t/ha)	Protein yield (t/ha)	Yield (t/ha)	Protein yield (t/ha)
‘Lissabon’	3.11	1.07	3.90	1.29	3.51	1.18
‘Merlin’	2.94	1.04	4.14	1.38	3.30	1.13
‘Cordoba’	2.83	0.97	4.09	1.30	3.62	1.20
‘Alma Ata’	2.82	1.02	4.00	1.33	–	–
‘Sultana’	2.82	1.06	3.90	1.33	3.38	1.22
‘Aligator’	2.76	0.97	4.19	1.39	3.40	1.14
‘ES Mentor’	–	–	4.76	1.71	3.89	1.38
Mean	2.88	1.02	4.14	1.71	3.52	1.21
Maturity	11–23 September		21–27 September		26 September–16 October	
Lodging	2.3–4.3 (medium)		1.0–1.4 (low)		1.2–3.3 (low–medium)	

[a]The SQR system rates soil on a scale of 0–100 according to crop yield potential, whereby generally a high rating (i.e. nearer to 100) indicates soils that are water-retentive due to a favourable fine soil texture.

Identifying Potential – an Example from Germany

These results show that there is potential in northern Europe, but much more detailed local studies are required to identify more precisely where soy has the potential to compete economically within farming systems. To achieve this, a German government-funded research project (Wilbois *et al.*, 2014) examined the performance of up to 48 soy cultivars in 99 field experiments conducted at 38 sites across Germany.

While weather varied between seasons, the ranking of the sites in terms of heat sums remained relatively constant over the years. The average CHU heat sum for May–September 2005–2013 at the 'warm' sites was 3182. The corresponding heat sums for the medium and cool sites were 2914 and 2740, respectively. Here we present an analysis of the likelihood of a yield level being reached for sites characterized on the basis of heat sum, based on an evaluation of yields of 99 soybean cultivar experiments on 33 sites in Fig. 7.1. Figure 7.2 presents the distribution of trial yields for the sites characterized as warm, temperate and cool using heat sums. In the warm region, 75% of the crops yielded in excess of 2.5 t/ha while the corresponding number for the cool region (average heat sum 2740) was just over 50%. The temperate region with an average heat sum of 2914 was also

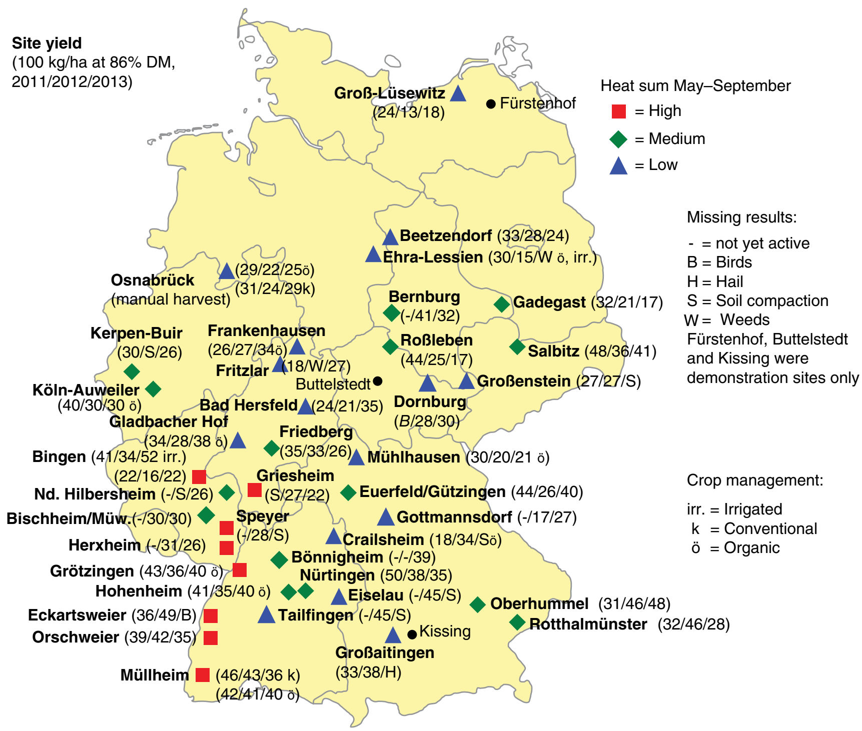

Fig. 7.1. The German field trial sites classified according to heat sum accumulation. The average yields for each site and year are shown (in units of 100 kg/ha). DM, Dry matter. (From Wilbois *et al.*, 2014.)

productive indicating that relatively small changes in heat sums between 2700 and 2900 have a significant effect on the likelihood of crop success.

These results support those of Hahn and Miedaner (2013) that show the effect of heat sums on yield level with indications of cultivar × environment interactions linked to the 00 and 000 classification (Fig. 7.3). In warmer regions the best yield is obtained by 00 cultivars (e.g. 'ES Mentor' in Region 1 with more than 3.5 t/ha) while in cooler regions 000 cultivars (e.g. 'Merlin' in Region 3) gave the highest yields but the overall yield level was lower.

From Wilbois *et al*. (2014) we can see that yields in German field trials may commonly vary from 2 t/ha or less in the north to 5 t/ha in the south, depending

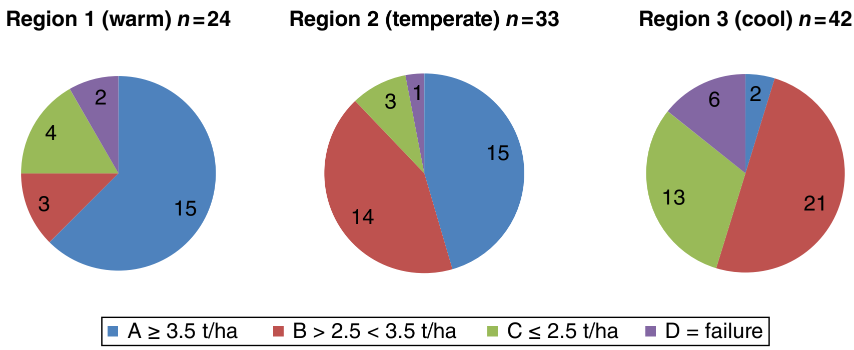

Fig. 7.2. Number of results (site mean) within three yield categories (3.5 t/ha or more, 2.5–3.5 t/ha, and less than 2.5 t/ha, plus failed crops for three regions as characterized by the heat sums into warm, medium (temperate) and cool. (From Wilbois *et al*., 2014.)

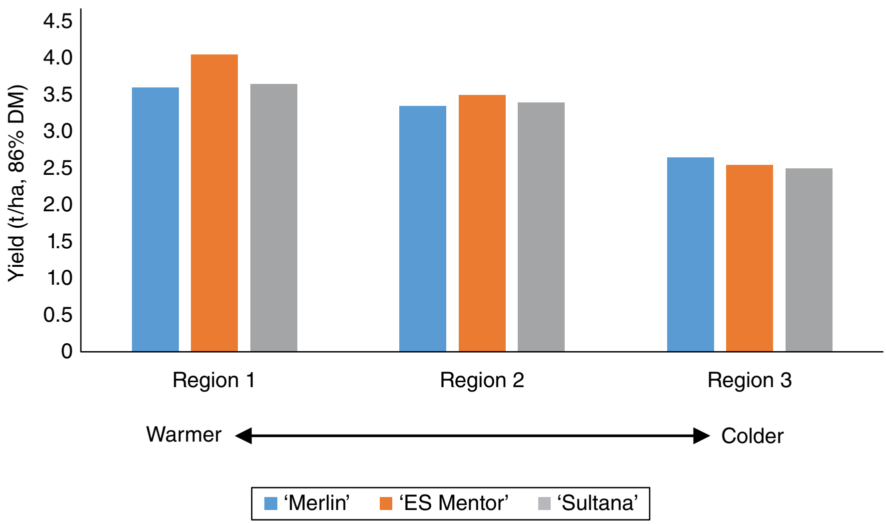

Fig. 7.3. Yields (grain at 14% moisture) of three soybean cultivars depending on regional heat sum. DM, Dry matter. (From Hahn and Miedaner, 2013.)

on heat sums and water supply in the summer. Our experience is that corresponding farm averages tend to vary from less than 2 t/ha to more than 3.5 t/ha, depending in particular on weather and soil conditions and weed management. Average yields in contract cultivation for organic tofu production in southern Germany have ranged from 2.1 t/ha to 2.8 t/ha in the last 10 years.

From a central European perspective, soybean yields in Scandinavia may seem to be low (see Table 7.2) but the protein yields are comparable to those of pea and faba bean, the amino acid profile is better, and there is the added benefit of the oil. There is, of course, also an increased risk of yield variations at these high latitudes due to climatic conditions. Soy is responding to development and yields are likely to increase by the use of improved cultivars and improved cropping systems in general.

Production Techniques

Soybean can be grown on a wide range of soils provided root development is not impeded by compaction. Optimum pH is about 6.5–7.0. Like other arable crops, soy performs well on water-retentive soils, so heavy soils are suitable if they warm up early in spring. Soils with a high mineral nitrogen supply, for example due to manure applications, are not suitable because of the suppression of nodulation and the risk of excessive vegetative growth.

Machinery used for cereals, oilseed rape and other legumes is also used for soy. Direct drilling can be used to reduce compaction by avoiding travel over prepared seedbeds. With conventional tillage, light seed drills followed by a light rolling are preferred under Scandinavian conditions to prevent compaction. Seed densities vary from 70–75 seeds/m^2 for 0000, 60–65 seeds/m^2 for 000 and 55–60 seeds/m^2 for 00 cultivars. In organic cultivation seed densities tend to be higher in order to compensate possible losses by intensive mechanical weeding. Row distances may vary from 12.5 cm (commonly used for cereals) to 75 cm (as is used for maize). Row distances in excess of 25 cm allow mechanical weed control and may be beneficial in northern Europe due to a better light penetration in the stand. Closer row spacing often gives taller unbranched plants, while rows 50–75 cm apart give bushy plants with 00 cultivars. Rows wider than 50 cm are not suitable for 000 and 0000 cultivars because of restricted branching. Emergence in difficult situations may be favoured by wider row distances (30–45 cm) due to the higher density in the rows. Precision seeding is also an option.

Inoculation with *Bradyrhizobium japonicum* is essential for optimum nitrogen fixation in soy. Some seed producers offer seeds that are inoculated and ready to sow. Where the farmer inoculates the seed, this must be done within 48 h of sowing, depending on the inoculum formulation. The process is quite easy, after a light soaking of the seeds, a fine-milled peat substrate containing the inoculum is added to them, thoroughly mixed and the seed is sown as normal. The inoculation of soy grown for the first time is twice that of subsequent crops. Pre-inoculated seeds should be additionally inoculated with the normal dose of fresh inoculum when sown on a field where soybean has never been grown. Even if rhizobia may survive in some soils for up to 10 years, inoculation is cost-effective also in further cultivations on a given field, because it provides yield and protein-content benefits.

The soy plant is sensitive to weed competition in its early development, especially if cold and wet weather prevails. Weed control can be achieved using herbicides or mechanical methods. No herbicides are approved for control of annual or perennial weeds in soy in the Nordic countries, but there are initiatives to extend the range of approved herbicides. In other European countries, a few herbicides for soybean are approved, but some weeds such as *Convolvulus* or bindweed, thistle and *Solanum nigrum* are not well controlled with them and land infested with these should not be used. One or two herbicide treatments are sufficient in most cases, including combinations of pre- and post-emergence treatments. Pendimethaline may adversely affect soybean where soils get waterlogged. Some cultivars are also sensitive to metribuzine (e.g. 'ES Mentor', 'ES Senator', 'Mavka') if soil splashes on the leaves due to intensive rainfall.

In organic farming, inter-row weed control should be carried out as soon as the rows are visible. The use of a stale seedbed (i.e. preparing a seedbed well in advance of sowing and destroying weed seedlings before sowing) will control weeds until inter-row cultivation is possible. A tined weeder may also be used within a week after sowing and before crop emergence. If successful, mechanical weed control may result in higher yields and earlier maturity because selective herbicides have side effects on the crop.

Until now, there have been few problems with fungal diseases in northern Europe. Some problems with insects affecting the plant at early growth stages due to slow emergence have been reported by farmers. In very warm years, Vanessa caterpillars may affect soybeans north of the Alps. An increase in cropping area might increase the need for pest control. Experience in regions where soy has been grown for several decades (e.g. in Austria) indicates that the risk of a build-up of problems as production expands is low.

At the more northerly end of the production zone, diseases may strike during emergence if there is prolonged cold and wet weather. Soy is susceptible to sclerotinia, especially if grown in rotations with rapeseed and sunflower. *Diaporthe*/*Phomopsis* may be a problem under wet conditions, especially for seed production (Hahn and Miedaner, 2013).

Harvest and Processing of Soybean for Food or Feed

In Scandinavia, soy matures in late September and is usually ready for harvest in early October. Further south, soy usually ripens during September and harvesting in September enables the sowing of a winter cereal as a succeeding crop. Grain moisture content can decrease rapidly at this time when the crop has lost its leaves. When the beans are loose in the pods, humidity may vary by 5% between the afternoon and night-time. Seeds with moisture contents over 18% are difficult to dry because of the size of the beans (they have to be dried in two steps). Nevertheless, after mid-October soybean should be harvested even if moisture exceeds 20%, because opportunities to harvest under dryer conditions are rare at this point.

The soy pod is relatively resistant to shatter with some differences between cultivars and is easy to harvest with standard combine harvesters. The first pod on each plant is often close to the soil surface which may result in field losses. Flexible headers are available making it possible to cut the plants 2–4 cm above the soil surface and thus reduce field losses significantly. Experienced drivers can reduce losses substantially also with conventional headers. Axial-flow combine harvesters are better for grain quality, breaking fewer seeds than the usual shaker-based machines.

If stored for 6 months or longer, drying should be used to bring moisture contents to 12% or lower. When used for food or seed, drying temperature in the grain should not exceed 40°C.

For cattle it is possible to use raw beans as feed, but for pigs and poultry, heat treatment is needed to remove antinutritional factors such as trypsin inhibitors. There are several technical options: roasting (or 'toasting') with direct or indirect heat or microwaves. Heat treatment may be combined with humidity and/or pressure. Technology from the USA, South Africa and Europe has opened up opportunities for small-scale on-farm processing. Roasting can, for instance, be done by machines from EST GmbH in Austria (EcoToast), Roastech in South Africa, and from the Dilts-Wetzel Manufacturing Co. in the USA.

These machines carry out dry roasting at about 100–400 kg/h and can easily be installed on farms. In roasting, a balance is set between the heat required to reduce inhibitors and avoidance of heat damage that reduces digestibility. Using a compact modular design, the EcoToast system from EST GmbH in Austria uses electricity and internal heat recovery to treat the soy in a hydro-thermal process so that the air is quite saturated with water at about 150°C, delivering a seed internal temperature of 100°C. The electricity usage is about 90 kWh/t. The Dilts-Wetzel machine also uses indirect heat to avoid exposing the seeds to high temperatures.

Cold pressing of the beans can be done with machines used for oilseed rape. It requires more energy than oilseed rape and wear on machines is high. About 50% of the oil content can be removed by cold pressing. Where a fat-free meal is required, pressing must be combined with solvent extraction. This is often too costly and technically demanding for small-scale producers. In organic agriculture, chemical solvents are not allowed. Account needs to be taken of the oil content in blending for feeding.

Soybean grown in northern Europe can be used for food purposes, resulting in high sensory and texture qualities. The quality for the food industry depends mainly on the cultivar, which might be set contractually by the buyer. There are different cultivars for drinks, tofu or natto. Soy intended for foods such as 'milk', tofu, ice cream and yoghurt, must fulfil quality requirements such as taste, processing quality criteria, texture and hygienic qualities.

Prospects for Soybean in Northern Europe

Crops of soy (Fig. 7.4) are becoming a common sight north of the Alps. We can expect that soybean cropping will become more common in central and northern

Fig. 7.4. A crop of soy growing in the Rhine valley, Germany. (Photo credit: Jürgen Recknagel.)

Europe. Agronomists in the Nordic and Baltic countries, including Germany and Poland, have in recent years identified soy as a 'new' crop that, under some conditions, can be cropped as far as 59°N. This understanding combined with premium markets for GM-free soybean opens opportunities for its production, especially for food purposes. We must emphasize that this outcome depends on science-based crop development to provide suitable cultivars.

Further south, particularly in southern Germany, France, Austria and the Balkans, soybean is of special interest in organic agriculture where it may resolve rotational problems with pea and faba bean by introducing another legume, increasing the overall yields and margins. There are local as well as state-sponsored initiatives to promote the growing of soy. One such initiative is the Danube Soya Association (www.donausoja.org), which is a partnership between public bodies, farmers, farm suppliers, processers and scientists aimed at growing soy in the Danube basin producing an alternative to imported soybean. It is supported by both EU member and non-member states in the Danube basin extending over a significant proportion of European territory where the crop can be grown well.

Recent information from the Danube Soya Association indicates that cultivation is expanding mainly in conventional agriculture, competing mainly with wheat, maize and oilseed rape for land. In warmer regions, maize may be the main competitor for land, if not restricted by corn rootworm regulations. In drier regions such as northern Bavaria, soybean competes mainly with rapeseed as well as several cereals. In regions with adequate rainfall, such as upper Austria, soybean competes well with cereals. Reichmuth and Schönberger (2012) reported that soybean competes well with current crops due to its positive effect on the following crop, which is normally winter wheat. The online margin calculator of the Bavarian State Institute for Agriculture (LfL) gives a detailed view of the competiveness of organic and conventionally produced soybeans compared to other crops for the different parts of Bavaria, based on statistical data of several years. Normally soybeans can compete easily with other grain legumes as well as with barley and oats. For practical growing decisions, the availability of a contract for production is often decisive for farmers. Since 2008, the price ratio between soybean and maize at about 2.5 supports expansion of soybean. In organic agriculture, soybean is often among the most competitive field crops as it does not need nitrogen input, its price is more than double that of conventional soybean and its yields are about the same when weeds are well controlled.

References

Ages (2016) Österreichische Beschreibende Sortenliste Sojabohne. Available at: www.ages.at (accessed 2 March 2016).

Brown, D.M. and Bootsma, A. (1993) Crop heat units for corn and other warm season crops in Ontario. Ontario Ministry of Agriculture and Food Factsheet. Available at: https://www.sojafoerderring.de/wp-content/uploads/2014/02/Berechnung-CHU-Uni-Guelph-Ontario.pdf (accessed 17 October 2016).

Copa Cogeca (2015) EU 28 Oilseeds Area and Production Estimates for Harvest 2014 and Sowing Intentions for Harvest 2015. Available at http://www.copa-cogeca.be/Crops.aspx (accessed 22 September 2015).

Deutscher Soja-Förderring (2015) Das Sojaportal für Deutschland. Available at: www.sojafoerderring.de/ (accessed 17 September 2015).

Drews, J. (2004) Die 'Nazi-Bohne'. Anbau, Verwendung und Auswirkung der Sojabohne im Deutschen Reich und Südosteuropa (1933–1945). Dissertation, Universität Münster, LIT Verlag, Münster, Germany, ISBN 978-3-8258-7513-8.

FAOSTAT (2016) Statistics Database of the Food and Agriculture Organization of the United Nations, Rome. Available at: http://faostat3.fao.org/home/E (accessed 2 March 2016).

Fogelberg, F. (2013) Soya beans and lupins 2012 – some results and conclusions of field experiments conducted for Scandinavian Seed AB. PowerPoint presentation at the Swedish Institute of Agricultural and Environmental Engineering (JTI), Uppsala, Sweden.

Haberlandt, F. (1878) Die Sojabohne, Ergebnisse der Studien und Versuche über die Anbauwürdigkeit dieser neu einzuführenden Kulturpflanze. Verlag von Carl Gerold's Sohn, Vienna, Austria.

Hahn, V. and Miedaner, T. (2013) Sojaanbau in der EU. DLG-Verlag, Frankfurt, Germany.

Holmberg, S. (1947) Sojaförädling vid Fiskeby (Soya bean breeding at Fiskeby). *Försök och Forskning: under redaktion av jordbrukets upplysningsnämnd* 1, 8–10.

Kaempfer, E. (1712) Amoenitatum exoticarum politico-physico-medicarum fasciculi V. Lemgoviae: Typis & Impensis Henrici Wilhelmi Meyeri, Aulae Lippiacae Typographi 1712.

Mechtler, K. and Hendler, M. (2010) Ertrags- und Qualitätsentwicklung bei Öl- und Eiweißfrüchten in der Sortenwertprüfung. Tagungsband der 61. Jahrestagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, 23–25 November 2010. Herausgeber Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, pp. 79–86.

Reichmuth, J. and Schönberger, H. (2012) Soja: Der Star von morgen? *Top agrar* 8, 70–74.

Saatzucht Donau (2015) Zuchtprogramme in der Station Reichersberg: Sojabohne. Available at: www.saatzucht-donau.at/deutsch/ueberuns/ueberuns.htm (accessed 18 January 2015).

Shurtleff, W. and Aoyagi, A. (2007) History of soy in Europe (incl. Eastern Europe and the USSR (1597–mid-1980s). In: *A Special Report on the History of Soybeans and Soyfoods around the World. History of Soybeans and Soyfoods: 1100 BC to the 1980s*. Soyinfo Center, Lafayette, California. Available at: www.soyinfocenter.com/HSS/europe1.php (accessed 17 September 2015).

Vishnyakova, M. and Seferova, I. (2013) Soybean genetic resources for the production in the Non-Chernozem zone of the Russian Federation. *Legume Perspectives* 1, 7–9.

Wilbois, K.-P., Spiegel, A.-K., Asam, L., Balko, C., Becker, H., Berset, E., Butz, A., Haase, T., Habekuß, A., Hahn, V., Heß, J., Horneburg, B., Hüsing, B., Kohlbrecher, M., Littmann, C., Messmer, M., Miersch, M., Mindermann, A., Nußbaumer, H., Ordon, F., Recknagel, J., Schulz, H., Spory, K., Trautz, D., Unsleber, J., Vergara, M., Vogel, R., Vogt-Kaute, W., Wedemeier-Kremer, B., Zimmer, S. and Zurheide, T. (2014) *Ausweitung des Sojaanbaus in Deutschland durch züchterische Anpassung sowie pflanzenbauliche und verarbeitungstechnische Optimierung.* (*Expansion of Soybean Cultivation in Germany through Adaptation by Breeding as well as Optimization of Crop Production and Processing Technology*.) Forschungsinstitut für biologischen Landbau (FiBL), Frankfurt am Main, Germany.