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Organic soybean production in Hungary

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SUMMARY

Organic soy production, particularly for feedstuff in organic animal husbandry, is needed in Hungary and the EU regions. Soybean producing crop area in Hungary has increased in the last years, however, the agroecological potential would allow for a larger soybean production area. This study presents the soybean market in Hungary, and the role of soybeans in protein supply in food and feed, summarising the critical elements of organic soybean production from variety selection to marketing. During the field research, the effects of the agronomical environment on yield potential factors were examined. We aimed to determine how different row spacing and tillage systems affect organic soybean yields of different varieties, with particular attention to the dry region, and determine the specific methods and varieties of soybean that favour these areas. We found that the tillage (plough/grubber), the spacing (wide/narrow), and the variety effects were all significant on morphological variables. The most remarkable difference was seen in plant height and the number of pods per plant, while the number of nodes was also highly impacted by tillage treatment and variety. The nutrition variables were significantly different, mainly as an effect of tillage and spacing interaction with significantly different plant responses of varieties.

Keywords: *soybean; soya market; organic soybean cultivation; ploughing; reduced tillage*

INTRODUCTION

Global protein consumption is increasing dynamically, rising from 166 million tons to 244 million tons between 2000 and 2019, particularly in Asia and Africa (FAO Statistics, 2021). Overall, soya is an excellent feed supplement and one of the most important global trade commodities, resulting in a world production of 360 million tons in 2020 (Statista, 2022), 92% of which took place in the US, Argentina, Brazil, China, and India. Organic soya cultivation still covers a relatively small area but has doubled within three years to approximately 914,000 ha (FiBL Statistics, 2022), amounting to 0.5% of the total soya-growing area. The increasing demand for high-protein, chemical-free agricultural commodities is helping the organic soya-meal market to grow globally (AgenceBio, 2019; Andreoli et al., 2021). Increased consumer awareness of the high nutritional value of organic soya flour due to its high protein content is projected to promote the growth of the organic soya flour market (Chai et al., 2019). The area under soya cultivation in the EU has also increased, and the annual output is now almost three million tons (EU Comission, 2019). Domestic total soy production in the EU27+UK has shown considerable growth rates over recent years; however, it still needs to be higher to fulfill the demand for high-quality protein crops (EU Comission, 2020). While domestic output reached 2.7 million tons in 2020, the total used soy volume, including net imports, amounted to 30.3 million tons of soybean meal (SITC1 08131), 1.8 million tons of soybeans (SITC12222) and 2.7 million tons of soybean oil (SITC1 42111, 42119) (Kuepper and Stravens, 2022). More than 80% of the imported organic oilseed by-products originate from China. Ukraine, India, Togo, and Turkey also play an essential role in organic soya production. In 2019, the European Union imported 132,079 metric tons of soybeans (Willer et al., 2020). Thus, the market opportunities for soya cultivation in Europe are apparent, and there are additional possibilities for organic soya grown for human consumption (Voora et al., 2020). Cultivation in central and northern Europe is therefore also justified, as some estimates suggest that around 10% of Europe's arable land would need to be sown with conventional and organic soya to reach self-sufficiency in this crop (Nendel et al., 2023).

In Hungary, growing organic soya can play a significant role in diversifying organic arable land. While cereals are grown in approximately 40% of the almost 98,560 ha of organically farmed arable land, only 3% is used to grow protein crops that also fix nitrogen in the soil (KSH 1). Similar machinery requirements allow farmers to diversify their cropping system with soya without considerable technological investment. Soya can adapt to all non-extreme soil types, but it is demanding regarding soil moisture balance. If a compacted, waterproof layer has formed near the soil surface, drought damage will be much greater (Cartter and Hartwig, 1962). There was also intermittent water cover at one on-farm location, which led to a severe yield loss. At the same time, yields of 3–4 t ha^{-1} and more than 35% protein content can be achieved on soils with a humus content of less than 2% (Balikó et al., 2007). Weed control in a highly weed-contaminated area is a major challenge (Berki, 2020). Soil preparation without ploughing is becoming ever more popular, and according to our experience, soya seems well adapted to reduced tillage (Kiszonas, 2010; Bozóki, 2022).

With organic soya, there is only a moderate risk to plant health regarding pathogens. However, the damage

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caused by cotton bollworm (*Helicoverpa armigera* Hb), painted lady (*Vanessa cardui*), southern green stink bug (*Nezara viridula*), and brown marmorated stink bug (*Halyomorpha halysis*) are significant in some years, and wild damage may also be substantial. Mite infestations can also occur, but this problem varies in scale from year to year (Tetila et al., 2020). Weed control is a critical technical element (Dierauer, 2017). In organic farming, early weed control is of much greater importance (Fogelberg and Recknagel, 2021). It can include blind weeding with a tine harrow on the fourth day after sowing and further inter-row cultivation after the seedlings reach the cotyledon stage (Hunyadi and Drexler, 2016). However, efficient use of the comb harrow requires high-quality equipment, uniform sowing and germination, and appropriate soil conditions (Hunyadi and Földi, 2022). Unfortunately, the irrigated cultivation of soya is not currently typical in Hungary, although, without it, neither the crop yield potential nor the agronomic potential of the land can be realized in dry regions or dry growing seasons (Agrárunió, 2019). There is more emphasis on sustainable conservation tillage systems, even in soybean cultivation. This is crucial to test in organic farming as well because reduced tillage can improve soil fertility and reduce GHG emission (Böhler et al., 2018). Although the ideal row spacing for soybeans is 45 cm (Balikó, 2018; Nagy et al., 2019), due to machine availability constraints, this is not always feasible for farms; therefore, we decided to also study how soybean varieties tolerate narrower (12 cm) row spacing.

MATERIALS AND METHODS

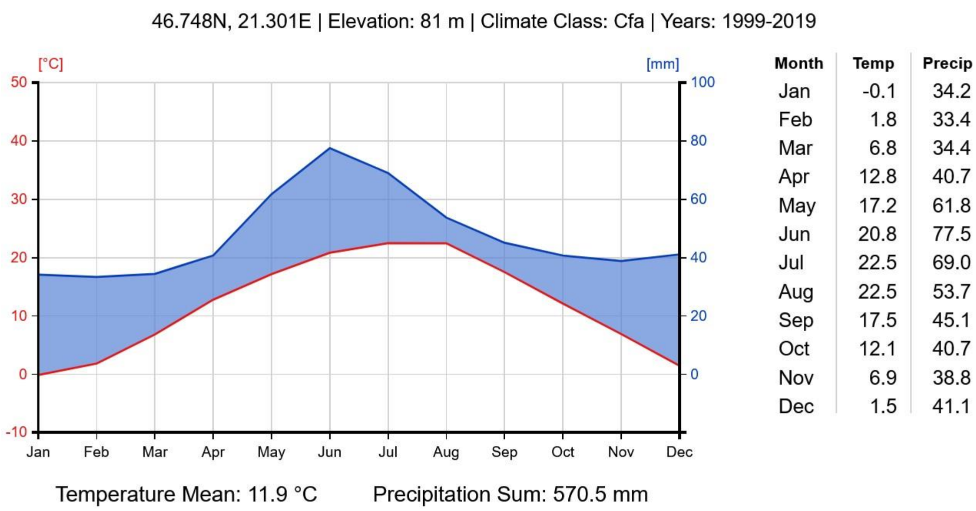
Analysis of production and market

To summarise the situation of soybean production, the nutrition values, and other properties which impact the Hungarian market position, we collected data from international and Hungarian professional databases, statistics, books, and articles, completed with the experience we gained in research projects related to soybean production (DiverIMPACTS). We have visualised the development and spatial variability of soybean production and yield across Hungarian NUTS 2 regions in the last twenty years, from 2000 to 2020. The visualisation was implemented using QGIS and R software.

Experimental area

The organic test field we present in this paper is located at the agricultural land-dominated landscape of the "Békési sík" on the South-Eastern part of the Great Hungarian Plain. Hot and dry continental climate characterizes the region (*Figure 1*), where Gleysols, Kastanozems, Chernozem (WRB 2014) soils with medium groundwater levels cover the lowland loess parent material (Csorba, 2021). The soil of the experimental plot is a sandy loam with a pH of 7.6 and organic matter content of 2.49%. In 2020, at the time of this research, there was a long drought period between the end of July and the end of August, with altogether 27 mm precipitation. During the vegetation period, the precipitation was 411 mm, and the mean temperature was 19.6 °C. The number of days above 30 °C was 42.

Figure 1: **Climate chart of the test site (Zepner et al., 2020)**



Study design

Soy was sown after spelt, in a depth of 4 cm. Steps of soil tillage were on one plot 35 cm deep ploughing (P) and seedbed tillage. Row spacing for sowing was 75 cm on the wide (W) and 12 cm on the narrow (N) plot. In the unploughed plot, seedbed preparation was made by grubber at 15 cm depth (G), followed by seedbed tillage. *Figure 2* presents the scheme of the experimental design.

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Figure 2: **The location of the plots and varieties managed by ploughing (P), grubber (G) with wide and narrow row spacing (W and N)**

P								G							
N				W				N				W			
Albenga	Bettina	Aires	Es Mentor	Albenga	Bettina	Aires	Es Mentor	Albenga	Bettina	Aires	Es Mentor	Albenga	Bettina	Aires	Es Mentor

On the plot with 12 cm row spacing, a weed comb was used only once during the growing season. On these plots, the weed pressure was higher, and there was no difference among varieties in this regard. In the other plots, weed comb and cultivator were used once. The strong weed growth reduced yield here.

At the time of flowering, a downy mildew infection appeared. The infection rate was 8–9%; Bettina and Aires varieties showed the highest susceptibility. Pests were not detected.

During the trial period, we recorded weather conditions, the time of flowering, the number the pods per plant, the number of seeds per pod, the number of branches per plant, and the plant heights in the vegetation period of growth. We surveyed the standing crop and compared the collected data on yield-influencing characteristics.

Data analysis

The effects of the variety, tillage (plough/grubber, P/G), and spacing (wide/narrow, W/N) were tested by 3-way MANOVA models. Dependent variables were:

- plant height,
- the number of branches per plant,
- the ln-transformed value of the number of pods per plant, and
- the ln-transformed value of the number of seeds per pod in the first model.

The ln-transformed values of the yield, the protein, and the oil content were used in the second model. The yield per plant with the oil and protein content (g) was calculated from the mass of 1000 seeds and the oil and protein percentages in the seeds. The normality of the model residuals was accepted by their skewness and kurtosis values, as their absolute values remained below one in all cases. The homogeneity of variances was satisfied based on the ratio of maximum and minimum variances, as they were all below 3 with high sample sizes (all were above 120).

In case of significant MANOVA overall result, follow-up univariate ANOVA models were run with Bonferroni's correction. Finally, homogeneous groups were separated by Tukey's post hoc tests. Statistical analysis was performed using IBM SPSS v27 (Armonk, 2020).

RESULTS AND DISCUSSION

Soya production and market

In Hungary, soya has become the dominant leguminous crop plant. Following a surge of soya cultivation in the 1980s, the next big increase came in 2015 as a result of financial support coupled to yield (*Table 1*).

Table 1: **Soya production and the soya market in Hungary**

Area	2015	2016	2017	2018	2019	2020
Harvested area (ha)	72 500	61 029	75 667	63 000	58 200	59 000
Yield average (t ha^{-1})	2.0	3.0	2.4	2.8	2.9	2.5
Total yield (t)	145 853	184 725	179 282	168 000	169 600	165 757
Imports (t)	140 000	144 458	166 872	155 335	148 947	163 168
Exports (t)	55 870	89 323	131 544	51 400	89 865	105 486
Organic soya area (ha)						
Harvested area (ha)	1245	1200	1542	1540	1800	1840
Yield average (t ha^{-1})	1.9	2.6	1.3	1.54	1.46	n.a.

At that time, more than 77,000 ha were cultivated by 5,200 farms, but due to unfavourable weather conditions and a lack of experience among new entrants, average yields fell short of two tons per hectare, discouraging production. In the following years, the area under cultivation decreased until it stabilized at around 60,000 ha, but by that stage, yields were already approaching three tons per hectare (KSH

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2). As the table shows, Hungary's soya exports are also significant. According to the CSO data for 2019, the largest buyers of Hungarian soybean (SITC 2222) are Austria and Germany, which together account for approximately 90% of exports. Regarding imports, Ukraine, Serbia, Croatia, and Romania are Hungary's most significant partners in importing soya, as both source and transit countries (about 120,000 tons). Soya meal (SITC 08131) imports to Hungary (430,000 t) predominantly (about 70%) arrive via Slovenia (the port of Koper) and to a lesser extent via Germany and Italy (Popp and Fári, 2016). Since 2013 GM-free soya prices were 20–30% higher than the price of GM soya. The poultry sector, which consumes a high proportion of soya products, has been particularly affected by this. Some domestic soya products of poultry farms continue to go to export markets that pay the non-GM pricing, chiefly Germany, Italy, Austria, and France. This has a negative effect on sustainability.

Given the changing climatic and soil conditions for soya, Hungary's typical growing areas have developed in previous decades. The main soya growing areas are Baranya, Tolna, Veszprém, Vas, Bács-Kiskun, Győr-Moson-Sopron, Zala, Békés, Borsod-Abaúj-Zemplén and Hajdú-Bihar counties. In addition to the previously dominant Southern Transdanubia, there has been a significant increase in the area of Western Transdanubia in recent years. The Southern Great Plain will become increasingly important, and a smaller production area has also developed in Northern Hungary (*Figures 3* and *4*).

Figure 3: **The location of NUTS 2 and 3 regions in Hungary. Colours show the area of crop fields in the NUTS 2 regions in 2020**
Source: KSH 3

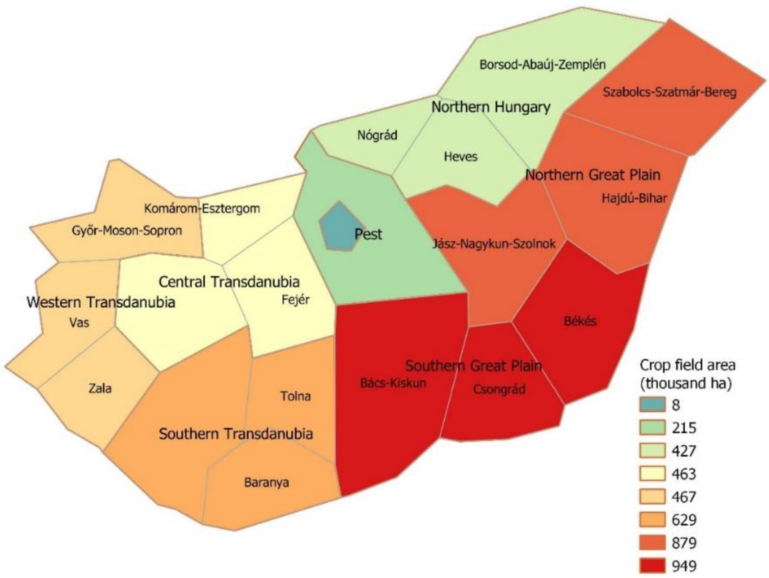
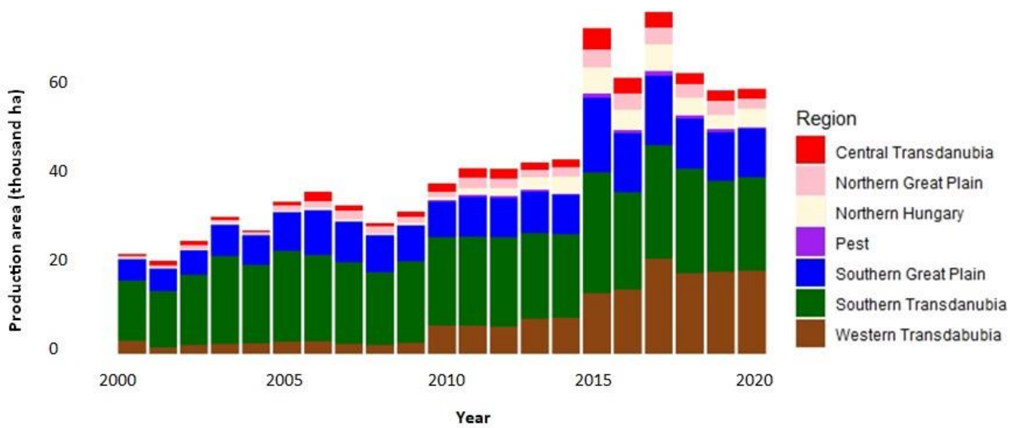


Figure 4: **Soya production area (ha) in the NUTS 2 regions of Hungary (ha)**
Source of data: KSH 2



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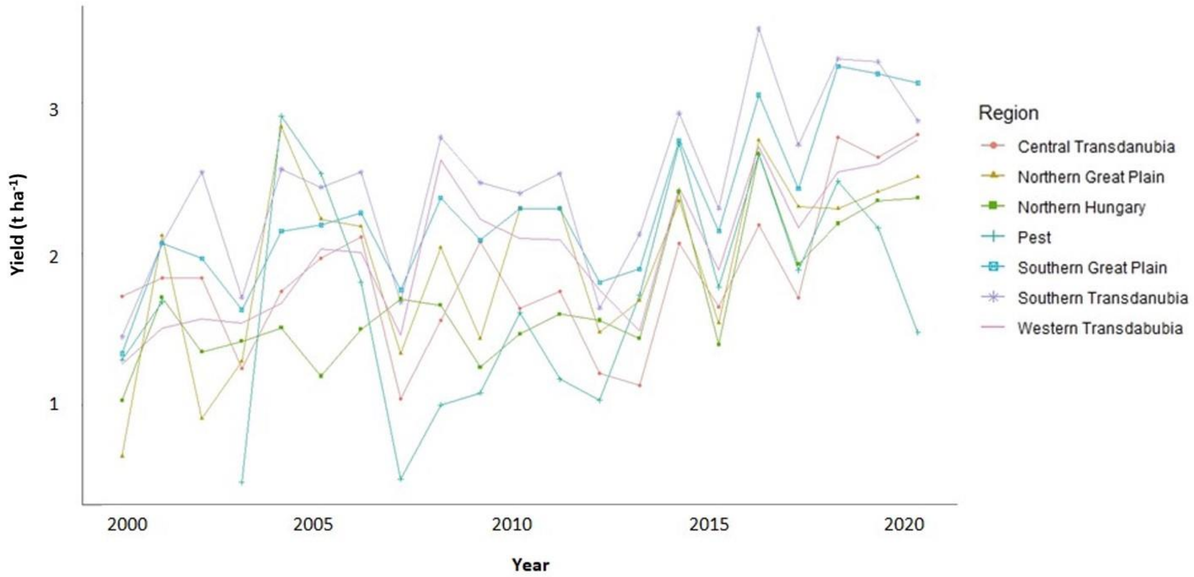
Yield averages vary among regions but are generally highest in Southern Transdanubia. At the same time, it is worth noting that the Southern Great Plain has been catching up in recent years, while yield averages are lower in the Northern Great Plain and Central Hungary (*Figure 5*).

Figure 5: **Yield averages in the NUTS 2 regions of Hungary. Source of data: KSH 2**



Soya production in Hungary has not increased significantly compared to previous years, and the area under organic soya production has also stagnated. While in Austria, for instance, 5% of arable land is used to grow soya, and almost 40% of that is organic, in Hungary, only 1.5% of arable land is used to grow soya, and only 5% of this is organic. By 2019, there had been a significant increase in Hungary's most important organic livestock sectors, which has led to an increase in demand for organic feed. Although it declined again in 2020, growing export demand can be expected to parallel domestic fluctuations, which justifies an increase in production volumes, despite the high risk. It is a positive sign that certified organic Hungarian feed producers have also begun to establish new product lines in the last years (for instance, in Ajka and Tiszakécske). Hopefully, this will also contribute to the stability of the domestic organic soya sector. However, further integration between stakeholders of the organic sector is essential in this regard since both domestic processing and sales and exports need to be based on a predictable and workable volume.

Field experiments

Morphological characteristics

The MANOVA overall result was significant (Wilk's lambda= 0.91; 0.73 and 0.23 for tillage treatment (plough/grubber, P/G), variety and spacing effect (wide/narrow, W/N), respectively, all with $p<0.001$). Meanwhile, all 2-way and 3-way interactions were significant (Wilk's lambda< 0.94; all with $p< 0.001$).

The follow-up univariate ANOVA with Bonferroni's correction resulted in significant tillage treatment effects (P/G) in cases of plant height, the number of branches and pods ($F(1,464)>12.12$; $p<0.001$), but not for the number of seeds ($F(1,464)=0.515$; $p=0.48$). The variety effect was also significant for all the variables of plant height, the number of branches, pods, and seeds ($F(3,464)>10.88$; $p<0.001$), together with significant interaction for all the variables ($F(3,232)>5.32$; $p<0.01$). However, the spacing effect (W/N) was significant only in the case of plant height (height: $F(1,464)=34.93$; $p<0.001$), and it was not significant for any of the other variables ($F(1,464)<2.55$; $p>0.1$). The interaction effect was significant in most of the 2-way and 3-way interactions ($p<0.05$), as presented in *Table 2*.

Yield and nutrient content

The MANOVA overall result was significant only for the variety effect (Wilk's lambda= 0.93; $p< 0.001$) and not significant for tillage treatment (P/G) and spacing effects (N/W) (Wilk's lambda>0.99; $p>0.43$) with also little treatment*variety interaction (Wilk's lambda> 0.99; $p= 0.084$). Nevertheless, all 2-way and 3-way interactions with spacing (WN) were highly significant (Wilk's lambda< 0.96; all with $p<0.001$), except spacing*treatment interaction, which was only slightly significant with Wilk's lambda= 0.99; $p=0.04$).

The follow-up univariate ANOVA with Bonferroni's correction detected a significant tillage treatment effect (P/G) for yield and protein and oil content ($F(3,464)>5.03$; $p<0.001$) with significant 2-way and 3-way interactions ($F(3,464)>6.04$; $p<0.001$), except for spacing*treatment interactions which were not significant ($F(1;464)<5.37$; $p>0.05$). The fact that the spacing effect was not significant, but its

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interactions were significant indicates that the interaction effects might have masked the (probably significant) spacing effect. Whether it is the case can be found out with the comparisons at factor combination levels that were performed, and the results are shown in *Table 3*.

Table 2: **The mean ± SD of the morphological variables of soybean. Different letters are for significantly different groups in comparison of varieties, within wide or narrow spacing of plough or grubber treated groups; while significantly higher values as an effect of tillage treatment are in bold and stars are for significantly higher values as an effect of spacing (Tukey's p<0.05)**

Variety/ cultivation1	Plant high (cm)	Nodes/plant	Pods/ plant	Seeds/ plant
with P/W				
Albenga	81.4 ± 5.8 c	11.4 ± 2.3 ab	32.7 ± 19.5 a	62.1 ± 44.3 b
Bettina	*79.5 ± 4.4 c	12.7 ± 2.4 b	36.5 ± 16.5 a	55.3 ± 28.2 b
Aires	72.2 ± 11.3 b	12.1 ± 2.3 b	26.8 ± 9.8 a	36.9 ± 15.8 a
Es Mentor	46.7 ± 6.5 a	10.5 ± 2.0 a	33.9 ± 16.6 a	***62.1 ± 30.3 b**
with P/N				
Albenga	82.4 ± 4.7 c	***13.7 ± 1.9 c**	30.8 ± 17.5 a	**54.0 ± 28.2 b**
Bettina	**73.7 ± 6.9 b**	13.4 ± 2.5 bc	46.6 ± 18.3 b	*72.5 ± 28.5 c
Aires	*81.8 ± 7.1 c	12.1 ± 2.0 b	33.0 ± 14.2 a	*65.7 ± 29.2 bc
Es Mentor	47.9 ± 7.9 a	10.6 ± 2.2 a	24.7 ± 13.4 a	38.5 ± 20.4 a
with G/W				
Albenga	**87.6 ± 7.7** c	***15.4 ± 2.8 c**	***46 ± 17.8 bc**	*65.0 ± 27.2 b
Bettina	*77.4 ± 5.4 b	13.7 ± 2.3 b	47.2 ± 18.6 c	**74.5 ± 32.2 b**
Aires	**80.9 ± 8.3 b**	13.6 ± 2.2 b	35.9 ± 17.2 ab	**58.8 ± 30.8 ab**
Es Mentor	**52.4 ± 4.8 a**	11.8 ± 2.1 a	32.8 ± 14.3 a	44.9 ± 20.0 a
with G/N				
Albenga	**91.1 ± 8.4 c**	11.8 ± 2.7 a	25.8 ± 11.8 a	34.5 ± 20.0 a
Bettina	64.5 ± 10.2 a	***15.4 ± 2.3 b**	50.8 ± 20.9 b	70.9 ± 36.7 c
Aires	***94.7 ± 8.4 c**	12.9 ± 2.2 a	26.4 ± 10.5 a	49.0 ± 23.8 b
Es Mentor	***74.1 ± 7.1 b**	**12.2 ± 1.8 a**	**39.2 ± 15.5 b**	**58.0 ± 19.8 bc**

[1]P = tillage with plough, G= tillage with grubber, W=wide space distance, N = narrow space distance

Table 3: **The mean ± SD of the yield and nutrient content of soybean. Different letters are for significantly different groups in comparison of varieties, within wide or narrow spacing of plough or grubber treated groups; while significantly higher values as an effect of tillage treatment are in bold and stars are for significantly higher values as an effect of spacing (Tukey's p<0.05)**

Variety/cultivation1	Yield/plant (g)	Protein content (g)	Oil content (g)
with P/W			
Albenga	10.0 ± 7.1 ab	3.7 ± 2.6 ab	2.4 ± 1.7 a
Bettina	10.2 ± 5.2 b	3.8 ± 1.9 b	2.4 ± 1.2 a
Aires	6.7 ± 2.9 a	2.4 ± 1.0 a	1.7 ± 0.7 a
Es Mentor	***10.7 ± 5.2 b**	***4.4 ± 2.1 b**	*2.4 ± 1.2 a
with P/N			
Albenga	**8.9 ± 4.6 ab**	**3.3 ± 1.7 ab**	2.0 ± 1.1 ab
Bettina	*13.3 ± 5.2 c	4.3 ± 1.7 b	*3.5 ± 1.4 c
Aires	*11.4 ± 5.1 bc	*4.4 ± 2.0 b	*2.7 ± 1.2 bc
Es Mentor	6.8 ± 3.6 a	2.9 ± 1.5 a	1.5 ± 0.8 a
with G/W			
Albenga	2.0 ± 1.1 ab	*4.2 ± 1.8 a	*2.8 ± 1.2 bc
Bettina	3.5 ± 1.4 c	4.2 ± 1.8 a	**3.4 ± 1.5 c**
Aires	2.7 ± 1.2 bc	**3.9 ± 2.0 a**	2.4 ± 1.2 ab
Es Mentor	*1.5 ± 0.8 a	3.2 ± 1.4 a	1.9 ± 0.8 a
with G/N			
Albenga	6.4 ± 3.7 a	2.4 ± 1.4 a	1.6 ± 0.9 a
Bettina	11.6 ± 6.0 b	3.8 ± 2.0 bc	3.0 ± 1.6 b
Aires	9.0 ± 4.4 b	3.3 ± 1.6 b	2.3 ± 1.1 b
Es Mentor	***10.9 ± 3.7 b**	***4.5 ± 1.5 c**	***2.5 ± 0.8 b**

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According to the statistical analysis, the tillage (plough/grubber), the spacing (wide/narrow), and the variety effects were all significant on organic soya's morphological variables. The most remarkable difference was seen in plant height and the number of pods per plant, while the number of nodes was also highly impacted by tillage treatment and variety. The nutrition variables were significantly different, mainly as an effect of tillage and spacing interaction with significantly different plant responses of varieties.

Albenga, Bettina, and Aires varieties tolerated well the sowing of the row distance used for cereals, probably because ploughing was more favorable in terms of mitigating weed pressure. Regarding yield, the most extensive cultivation technology (narrow row spacing, without plough) was best tolerated by Bettina and Mentor, although Bettina's protein content (32%) lagged far behind that of the other three varieties.

The protein content of Mentor proved to be the most stable, exceeding 40% in all cultivation methods. The oil content of the varieties exceeded 22%, and the Bettina and Aires varieties also had even more than 25%. In terms of oil content, Bettina was the most stable variety.

The combined effect of spacing and tillage method resulted in different qualitative and quantitative values according to the varieties. Albenga and Aires produced higher growth, node, pod and seed number, but less yield in unploughed wide plots, however, the quality variables were higher. In the case of Bettina variety, the lower morphological values resulted in less yield, but higher nutrition quality in wide unploughed plots. Es Mentor seems to favour narrow unploughed management, showing high morphological and nutrient values.

CONCLUSIONS

Organic soybean production is becoming increasingly important in the food supply throughout Europe. Although the acreage of land suitable for soya production grows, the risk of cultivation increases, too due to climate change, but choosing the suitable site and the right variety, in harmony with agronomic methods, can mitigate this risk. In organic farming, the optimalisation of the cultivation site and method is even more central, as it is the most viable way to influence the yield and quality of the crop besides variety selection.

As conservation tillage with less soil disturbance has a much better long-term effect on soil conditions and is more economically advantageous, it is worthwhile to continue testing the varieties adaptation capacities to extensive cultivation technology with conservation tillage methods.

According to our findings, the tillage method did not influence yield and protein content of selected soybean varieties. Several varieties had yielded more than 2 t ha^{-1}, and protein content was higher than 35% for most of the studied varieties. The protein content of the variety ES Mentor was the most reliable, with more than 40%, and the variety Bettina had the highest yield.

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