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Effect of two seeding rates on yield and yield components of winter and spring faba bean

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ABSTRACT

In Central European cropping systems, there is increasing interest in winter faba bean (*Vicia faba* L. minor), which is traditionally used as a spring crop. But limited knowledge on yield and yield formation and optimum seeding rate exist. Therefore, the purpose of this assessment was to compare soil coverage, yield and yield components of two winter faba bean varieties (Diva and Hiverna) with a spring faba bean (Alexia) with two seeding rates (SR), 25 versus 50 germinable seeds m⁻² (S), in a two-year field experiment under Pannonian climate conditions in eastern Austria. Both winter faba bean varieties produced a high grain yield with 25 S, whereas that of Alexia tended to be higher with 50 S. The grain yield of Diva and Hiverna was with 25 S and that of Diva also with 50 S higher than that of Alexia. The higher SR caused in winter faba beans a higher intraspecific competition resulting in less stems plant⁻¹. Pod density of Alexia was higher with 50 S compared to 25 S, while grains pod⁻¹ and thousand kernel weight of all three varieties were not affected by SR. Results show that winter faba bean can be sown in Central Europe with lower seeding rates compared to spring faba bean without suffering a grain yield loss.

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Vicia faba; pods; grains; stems; thousand-kernel weight



Introduction

Grain legumes are important to break crops in cereal-based crop rotations. Including them into crop rotation can interrupt disease and pest cycles, improve soil fertility through nitrogen (N) fixation and carbon sequestration and reduce greenhouse gas emissions and use of fossil energy (Robson et al. 2002). These system-internal outputs are often underestimated, while the market output of grain legumes per unit area is relatively low and volatile. Consequently, grain legume cultivation in Europe has declined from 5.8 to 1.8 Mha between 1961 and 2013, whereas production still increased in that period from 3.3 to 4.2 Mt (Zander et al. 2016). This results in a deficit of vegetal proteins and dependency on imports like soybean, of which around two-thirds used in the European feed industry are imported (Henseler et al. 2013).

Strategies are therefore needed to increase grain legume production in Europe; among those are introducing new grain legumes more adapted to drought like

chickpea (Neugschwandtner et al. 2013), using grain legumes in intercropping systems with cereals (Neugschwandtner and Kaul 2014) and shifting from spring-sowing to autumn-sowing of grain legumes (Neugschwandtner et al. 2019a). Currently, most grain legumes in Central Europe are spring forms. Winter forms, e.g. of faba bean (*Vicia faba* L. minor) are cultivated in England on about 30–50 kha and in north-western France on about 10 kha, but they are almost non-existent in Central Europe (van het Loo and Sass 2017). With increasing tolerance to frost due to breeding efforts and in the presence of climatic warming, however, this crop has potential for expanding its range in Europe (Link et al. 2010).

The benefits of autumn-sown crops are generally a higher yield potential and higher yield stability than spring-sown crops. For example, in Austria, long-term yields of winter barley in organic or in conventional production by one fifth or one third higher than spring barley yields, respectively (Brückler et al. 2017). The

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higher yield stability of autumn-sown crops results from their quick regrowth after winter, making them less exposed to water deficits in spring (Reckling et al. 2018). The most drought-sensitive growth stages for faba bean are flowering, early podding and grain filling (Mwanamwenge et al. 1999), and high temperatures at flowering depress yield levels of faba bean (Bodner et al. 2018). With autumn-sowing, these growth stages occur earlier before the onset of high late-spring and early-summer temperatures and also last longer, as shown for winter versus spring faba bean (Neugschwandtner et al. 2015b). The extension of the flowering period is an important trait for achieving high yields (Bodner et al. 2018). Similar observations have been made for autumn- versus spring-sown facultative wheat (Neugschwandtner et al. 2015a). Winter forms of faba bean and pea were shown to have higher above-ground biomass, grain yields (Neugschwandtner et al. 2019a) and higher N yields and N fixation than their spring forms (Neugschwandtner et al. 2021).

Besides sowing date, other agronomic practices need to be addressed for the improvement of faba bean production in European cropping systems, among those is optimizing plant density (Karkanis et al. 2018). Plant density and plant distribution patterns affect crop growth rate, seed filling rate and yield formation of faba bean (Stützel and Aufhammer 1992). A longstanding recommendation for spring faba bean in Germany is a sowing density of 35 seeds m^{-2} , taking seed cost and stability of plant stands into account, but a higher seeding rate of 40–50 seeds m^{-2} might also be economically reasonable (Sauermann 2017). Also Kulig et al. (2009) recommended 35–50 seeds m^{-2} for Polish conditions. Whereas Geisler (1983) recommended 50–60 seeds m^{-2} for spring faba bean, arguing that with lower crop densities a high yield can only be obtained with a high number of pods plant^{-1} , and pod set is strongly affected by environmental conditions.

Yield components of faba bean during crop development are formed as follows: after germination, the main stem and possibly also side stems are formed. The first nodes have no floral initials, which start to form from nodes 5 or 6 on. The formation of flowers and thus later of pods corresponds to the growth of the stems. Pods develop according to the timing of flowering. They are therefore initialized at different developmental stages during growth. Number of pods plant^{-1} , pods stem^{-1} and grains pod^{-1} are subject to strong fluctuations and are affected by environmental conditions and by plant cultivation measures like sowing time and seeding density (Geisler 1983; Kulig et al. 2011).

Limited knowledge is available of yield formation in general and optimal seeding rates, particularly, in

winter faba bean under Central European growing conditions. Recommendations for spring faba bean certainly do not fit, as its yield component pattern is different: spring faba bean generally produces one stem plant^{-1} . Multiple stems are rare, whereas winter faba beans show stronger branching. Further, essential stages of vegetative and generative development of winter faba bean fall in a cooler, usually rainier season (Geisler 1983). Therefore, the aim of this study compares winter and spring faba bean in eastern Austria in order to gain knowledge of yield and yield formation under contrasting sowing dates as affected by seeding rate.

Material and methods

Environmental conditions

The field of the experimental farm Groß-Enzersdorf of BOKU University is located in Raasdorf (48° 14' N, 16° 35' E; 154 m above sea level). The silty loam soil is classified as a chernozem of alluvial origin and rich in calcareous sediments. It has a $\text{pH}_{\text{CaCl}_2}$ of 7.6 and an organic substance content of 2.2–2.3%.

The long-term annual means of temperature and precipitation are 10.7°C and 543 mm (1983–2012). The temperature in the vegetation period of winter crops (October to July) in the two experimental years (2013/2014 and 2014/2015) was above the long-term average and precipitation in the first year was above and in the second was below the long-term average. The first experimental year was dry from October to January but considerably higher amounts of precipitation occurred in April, May and July. In the second experimental year, higher amounts of precipitation occurred in December and January but low values in autumn and from February on. For monthly means of temperature and rainfall, see Neugschwandtner et al. (2019a).

Experimental setup and treatments

A two factorial experiment with the factors variety (V) and seeding rate (SR) was performed in the years (Y) 2013/14 and 2014/15. The experimental setup was a randomized complete block design with four replications (plot size: 10 × 1.5 m).

The winter faba bean varieties Diva and Hiverna were sown on 17 October 2013 and on 13 October 2014; the spring faba bean Alexia on 4 March 2014 and on 10 March 2015. SR was 25 or 50 germinable seeds m^{-2} (25 S or 50 S). Harvest was performed in 2013/2014 for both winter and spring faba beans on 7 July. In 2014/2015, winter faba bean was ripe on 7 July and spring

faba bean on 13 July. The winter survival of winter faba bean varieties was high in both years with a mean over both varieties of 95% (2013/2014) and 94% (2014/2015).

The countries of origin of the varieties (with breeding companies and year of release noted in parentheses) are for Diva France (Agri-Obtentions, 2001), for Hiverna Germany (breeder: Littmann, now: Norddeutsche Pflanzenzucht Hans-Georg Lembke KG, 1986) and for Alexia Austria (Saatzucht Gleisdorf, 2007).

Plots were not fertilized. Details for seedbed preparation, sowing, soil mineral nitrogen at sowing and plant protection are given in Neugschwandtner et al. (2019a).

Experimental measurements

Soil cover of the crops during the growing period was measured by image analysis of digital colour pictures according to Richardson et al. (2001) and Karcher and Richardson (2005) using SigmaScan Pro5 software. Plants were harvested by manually cutting 2 m² at the soil surface and divided in grains, pod walls and stems plus leaves to determine yield fractions after drying at 105°C for 24 h. Shed leaves were not sampled. For soybean, it has been shown that the actual harvest index correlates highly significantly with the apparent HI, which is based on the above-ground biomass of mature plant without shed plant parts, and therefore the actual harvest index should permit valid comparison of treatments (Schapaugh and Wilcox 1980).

The following yield components were measured or calculated: plant density (plants m⁻²), stem density (stems m⁻²), stems plant⁻¹, pod density (pods m⁻²), pods plant⁻¹, pods stem⁻¹, thousand kernel weight (TKW), grains plant⁻¹, grains stem⁻¹, grains pod⁻¹, grain density (grains m⁻²), grain yield plant⁻¹, grain yield stem⁻¹ and grain yield pod⁻¹.

Statistics

Analysis of variance with subsequent multiple comparisons of means were performed using SAS version 9.2. Means were separated by least significant differences (LSD), when the F-test indicated factorial effects on the significance level of $p < 0.05$.

Results

Soil coverage

Soil coverage of winter faba bean varieties before the onset of winter rest was 4.9% in 2013/2014 or 7.2% in 2014/2015 (means over both V and SR), and it was

higher with 50 S compared to 25 for both varieties in 2013/2014 and for Hiverna in 2014/2015 (Figure 1(A, B)). The soil coverage of winter faba bean varieties quickly increased in spring in both years, with soil coverage of > 90% with both SR at the end of April 2014, while Alexia had 9% with 25 S or 18% with 50 S, and in mid-May 2015, when Alexia had 38% with 25 S or 86% with 50 S. The soil coverage of winter faba bean varieties up to late April 2014 or early May 2015 was higher with 50 S compared to 25 S. Hiverna had higher values in early spring 2015 than Diva. In both years, Alexia reached a soil coverage > 20% not before early May and differences between SR were smaller compared to winter faba bean varieties.

Yields and harvest index

The mean yield values over all V, SR and Y were: Above-ground dry matter – 708 g m⁻², grain yield – 272 g m⁻², pod wall yield – 58.9 g m⁻², yield of stems plus leaves – 377 g m⁻², total residue yield – 436 g m⁻², harvest index – 39.0%.

The above-ground dry matter yield was ranked as follows: 25 S – Hiverna, Diva > Alexia, 50 S – Hiverna > Diva > Alexia, and for Alexia, it was 1.26-fold and for Hiverna 1.11-fold higher with 50 S than with 25 S. Diva had a higher above-ground dry matter in 2013/2014 than in 2014/2015, that of Alexia and Hiverna did not differ between years. Across all SR and Y, the above-ground dry matter yield of Diva was 1.66-fold and that of Hiverna 1.84-fold higher than that of Alexia (Figure 2(A,B)).

The grain yield was ranked as follows: 25 S – Diva > Hiverna > Alexia, 50 S – Diva ≥ Hiverna ≥ Alexia. It tended to be higher for Alexia with 50 S than with 25 S (1.29-fold, n. s.) and with 25 S was higher than with 50 S for Diva, with no difference between SR for Hiverna. The grain yield did not differ between Y. Over all SR and Y, the grain yield of Diva was 1.71-fold and that of Hiverna 1.33-fold higher than that of Alexia (Figure 2(C,D)).

The pod wall yield was ranked as follows: Diva > Hiverna, Alexia; 2014/2015 > 2013/2014. It did not differ between SR (Figure 2(E,F)).

The yield of stems plus leaves (Figure 2(G,H)) and the total residues yield (Figure 2(I,J)) were ranked as follows: Hiverna > Diva > Alexia. They were 1.16-fold (stems plus leaves) and 1.23-fold (total residues yield) higher with 50 S than with 25 S, and both were higher for Diva in 2013/2014 than in 2014/2015.

The harvest index was ranked as follows: 2013/2014 – Alexia, Diva > Hiverna; 2014/2015 – Diva > Alexia > Hiverna; with no differences between SR (Figure 2(K,L)).

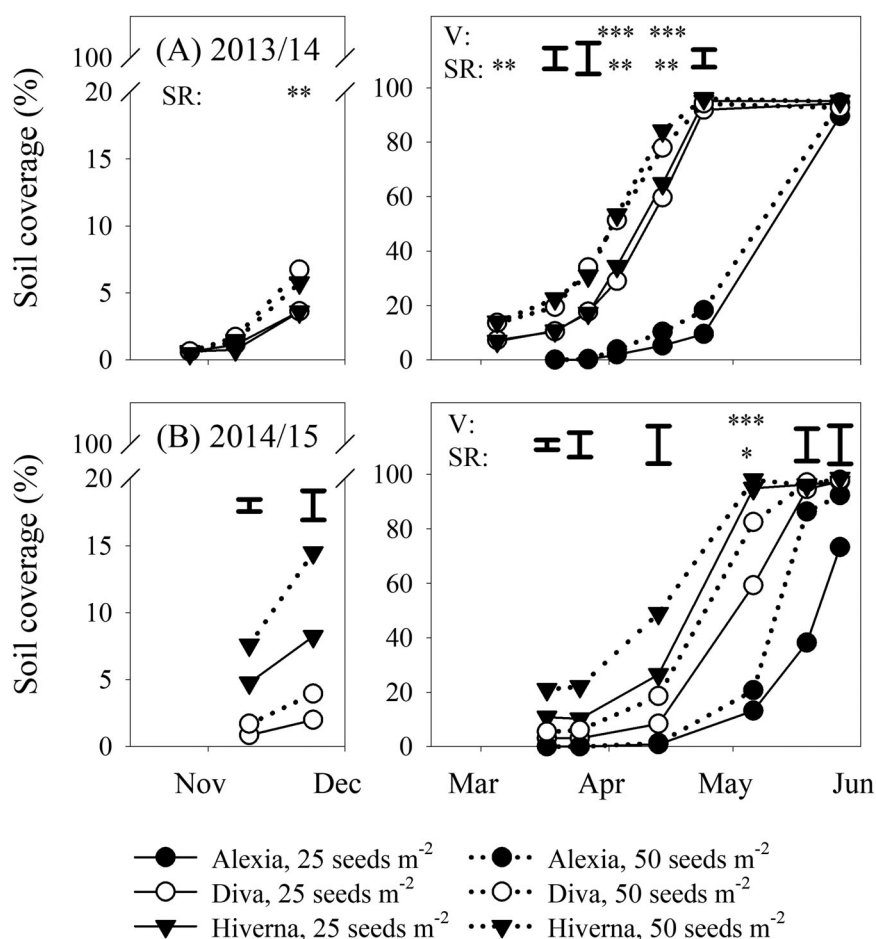


Figure 1. Effects of variety (V) × seeding rate (SR) on soil coverage in (A) 2013/2014 and (B) 2014/2015. Main effects of V or SR are significant at $p < 0.05$ (*), at $p < 0.01$ (**) and $p < 0.001$ (***). Error bars are LSD ($p < 0.05$) for the significant interactions of V × SR. Alexia is the spring faba bean, Diva and Hiverna are winter faba beans.

Yield components on the plant and pod level

The mean values for yield components focusing on plants and pods over all V, SR and Y were: plant density – 36.9 plants m^{-2} , stem density – 64.5 stems m^{-2} , stems $plant^{-1}$ – 1.89, pod density – 235 pods m^{-2} , pods $plant^{-1}$ – 7.41, pods $stem^{-1}$ – 4.24.

The plant density was ranked as follows: 2013/2014 – Alexia \geq Diva \geq Hiverna; 2014/2015 – Hiverna > Alexia > Diva; with a 1.82-fold higher plant density with 50 S than with 25 S. The plant density in 2013/2014 compared to 2014/2015 was higher for Diva and lower for Hiverna (Figure 2(M,N)).

The stem density was ranked as follows: Hiverna > Diva > Alexia, with Diva having a 1.68-fold and Hiverna a 1.83-fold higher stem density than Alexia (over both SR and Y). With 50 S, it was 1.38-fold higher than with 25 S (over both SR and Y). In the individual years, stem density was ranked as follows: 2013/2014 – Diva > Hiverna > Alexia; 2014/2015 – Hiverna > Diva > Alexia; with differences of stem density between years just for Diva (Figure 2(O,P)).

The number of stems $plant^{-1}$ did not differ between SR for Alexia but for Diva it was 1.23-fold and for Hiverna 1.46-fold higher with 25 S than with 50 S (mean over Y). Between years, it was higher for Hiverna in 2013/2013 than in 2014/2015 (Figure 2(Q,R)).

The pod density was ranked as follows: 25 S – Diva > Alexia, Hiverna; 50 S – Alexia \geq Diva \geq Hiverna, with no differences between years. For Alexia with 50 S, it was 1.26-fold higher than with 25 S, whereas the pod density of winter faba beans did not differ between SR (Figure 2(S,T)).

The number of pods $plant^{-1}$ was higher with 25 S than with 50 S and ranked for SR as follows: 25 S – Diva > Alexia, Hiverna; 50 S – Diva \geq Alexia \geq Hiverna; with lower values for Diva in 2013/2014 than in 2014/2015. The number of pods $plant^{-1}$ with 25 S compared to 50 S was 1.43-fold higher for Alexia, 2.00-fold higher for Diva and 1.73-fold higher for Hiverna (Figure 2(U,V)).

The number of pods $stem^{-1}$ ranked as follows: 25 S – Alexia > Diva > Hiverna; 50 S – Alexia > Diva, Hiverna, with lower values in 2013/2014 than in 2014/2015. The number of pods $stem^{-1}$ was higher

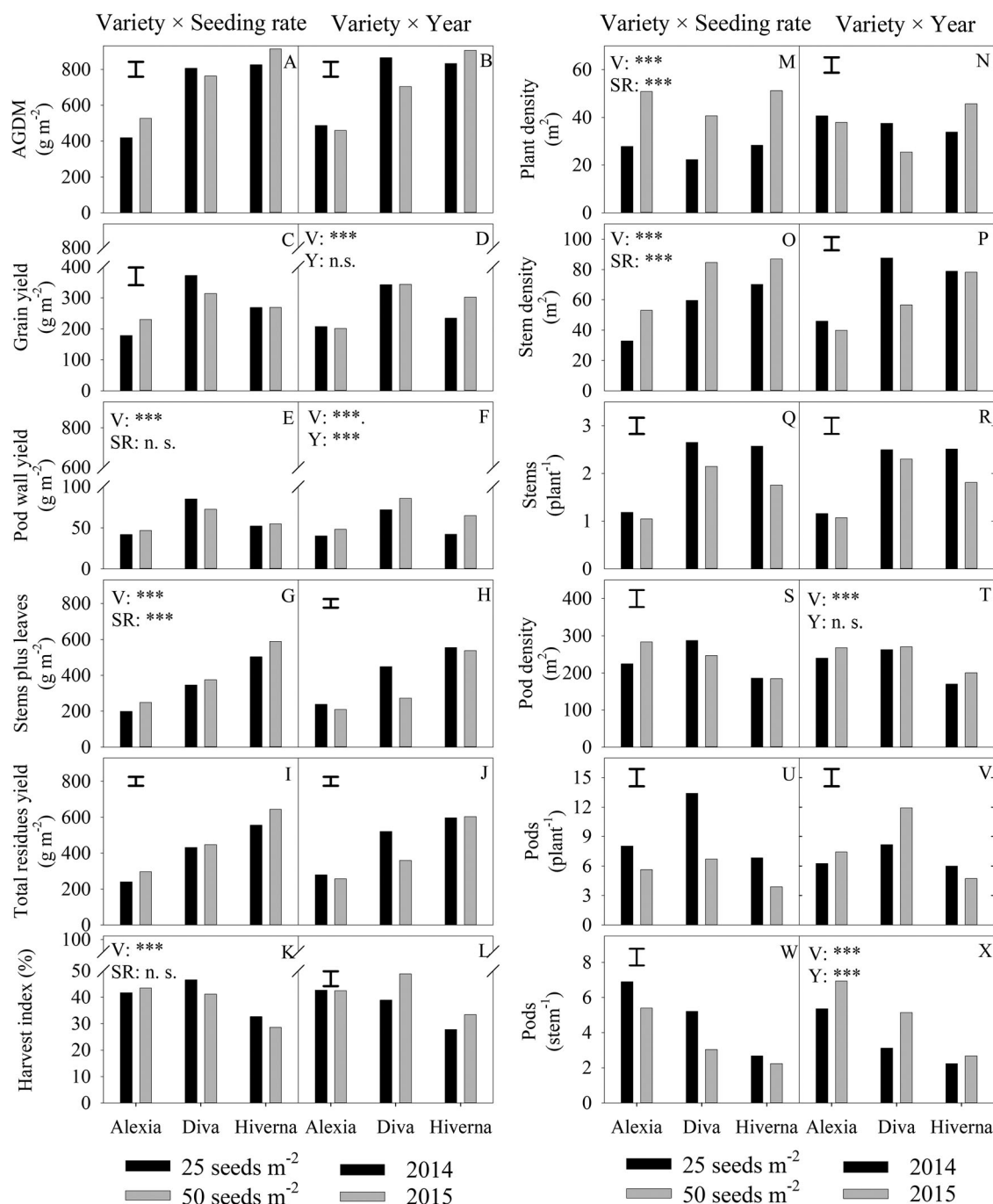


Figure 2. Effects of variety (V) × seeding rate (SR) or variety × year (Y) on: Yields of (A, B) above ground dry matter (AGDM), (C, D) grain, (E, F) pod walls, (G, H) stems plus leaves and (I, J) total residues; (K, L) harvest index; (M, N) plant density, (O, P) stem density, (Q, R) stems plant⁻¹, (S, T) pod density, (U, V) pods plant⁻¹, (W, X) pods stem⁻¹. Main effects of V, SR or Y are significant at $p < 0.001$ (***) or not significant (n. s.). Error bars are LSD ($p < 0.05$) for the significant interactions of V × SR or V × Y. Alexia is the spring faba bean, Diva and Hiverna are winter faba beans.

by 1.28-fold for Alexia, 1.71-fold for Diva and 1.19-fold for Hiverna (n. s. for Hiverna) with 25 S compared to 50 S (Figure 2(W,X)).

Yield components on the grain level

The mean values for yield components focusing on grains over all V, SR and Y were: TKW – 364 g, grain

density – 769 grains m⁻², grains plant⁻¹ – 24.5, grains stem⁻¹ – 13.7, grains pod⁻¹ – 3.24, grain yield plant⁻¹ – 8.69 g, grain yield stem⁻¹ – 4.60 g, grain yield pod⁻¹ – 1.17 g.

The TKW was ranked as follows: Hiverna > Diva > Alexia; with no differences between SR and higher values for Alexia and Diva in 2013/2014 than in 2014/2015 (Figure 3(A,B)).

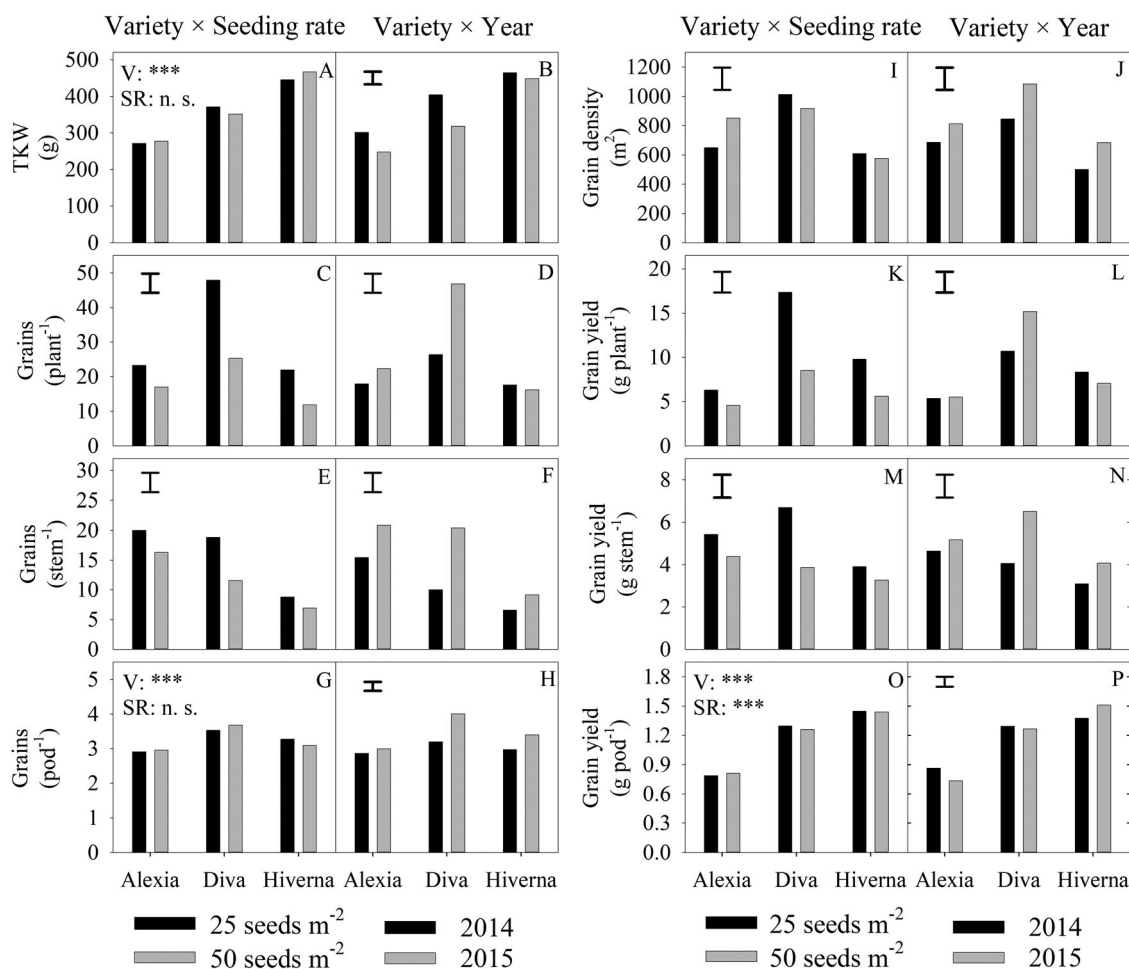


Figure 3. Effects of variety (V) × seeding rate (SR) or variety × year (Y) on: (A, B) Thousand kernel weight (TKW), (C, D) grains plant⁻¹, (E, F) grains stem⁻¹, (G, H) grains pod⁻¹, (I, J) grain density (m⁻²), (K, L) grain yield plant⁻¹, (M, N) grain yield stem⁻¹, (O, P) grain yield pod⁻¹. Main effects of V, SR or Y are significant at $p < 0.001$ (***) or not significant (n. s.). Error bars are LSD ($p < 0.05$) for the significant interactions of V × SR or V × Y. Alexia is the spring faba bean, Diva and Hiverna are winter faba beans.

The grain density was ranked as follows: 2013/2014 – Diva > Alexia > Hiverna; 2014/2015 – Diva > Alexia, Hiverna; with a lower grain density for Diva and Hiverna in 2013/2014 than in 2014/2015 and no differences between SR (Figure 3(I,J)).

The number of grains plant⁻¹ was ranked as follows: Diva > Alexia, Hiverna; 50 S > 25 S. The number of grains plant⁻¹ with 25 S compared to 50 S for Diva and Hiverna was 1.90-fold and 1.85-fold higher, whereas for Alexia it was only 1.37-fold higher. For Diva in 2013/2014, it was lower than in 2014/2015 (Figure 3(C,D)).

The number of grains stem⁻¹ was ranked as follows: 2013/2014 – Alexia, Diva > Hiverna; 2014/2015 – Alexia > Diva > Hiverna, with higher values in 2014/2015 than in 2013/2014 for Diva and Hiverna. The number of grains stem⁻¹ with 25 S was higher compared to 50 S for Alexia, considerably higher for Diva, but did not differ for Hiverna between SR (Figure 3(E,F)).

The number of grains pod⁻¹ was ranked as follows: 2013/2014 – Diva ≥ Hiverna ≥ Alexia; 2014/2015 – Diva > Hiverna > Alexia; with lower values in 2013/2014 than in 2014/2015 for Diva and Hiverna. The number of grains pod⁻¹ did not differ between SR (Figure 3(G,H)).

The grain yield plant⁻¹ was ranked for both SR as follows: Diva > Hiverna > Alexia. With 25 S compared to 50 S it was 1.38-fold higher for Alexia (n. s.), 2.04-fold higher for Diva and 1.75-fold higher for Hiverna. For Diva it was lower in 2013/2014 than in 2014/2015 (Figure 3(K,L)).

The grain yield stem⁻¹ was ranked as follows: 25S – Diva > Alexia > Hiverna; 50 S – Alexia ≥ Diva ≥ Hiverna. With 25 S compared to 50 S, it was 1.24-fold higher for Alexia (n. s.), 1.74-fold higher for Diva and 1.19-fold higher for Hiverna (n. s.). For Diva, it was lower in 2013/2014 than in 2014/2015 (Figure 3(M,N)).

The grain yield pod⁻¹ was ranked as follows: Hiverna > Diva > Alexia. It did not differ between SR. In 2013/

2014 compared to 2014/2015, it was higher for Alexia and lower for Hiverna (Figure 3(O,P)).

Discussion

Soil coverage by plants is important for weed suppression and for soil protection against erosion. The protective efficiency of faba bean starts at about 30% soil coverage (Klima and Wiśniowska-Kielian 2006). This value could not be reached by winter faba beans with both SR before winter. The fast increase of soil coverage of winter faba beans in early spring make them much more valuable for soil protection in that time period of the year compared to spring-sown varieties (Figure 1 (A,B)). Similar observations have been made for winter versus spring pea: Spring pea attained equal soil coverage as winter pea just a few weeks before harvest (Neugschwandtner et al. 2020). A higher SR causes higher soil coverage; thereby a higher soil protective efficiency can be expected. Furthermore, sowing of seeds with a higher TKW can result in higher soil coverage, probably due to higher emergence and/or higher early vigour (Neugschwandtner et al. 2019b).

Winter faba bean varieties produced a higher above-ground dry matter and grain yield than Alexia (n. s. for 50 S of Hiverna). Among winter varieties, Diva had a higher grain yield (n. s. for 50 S) and a higher harvest index than Hiverna, which produced more stems and leaves. A yield advantage has also been shown for autumn-sown compared to spring-sown winter-type faba bean in northern Germany (Herzog and Geisler 1991) and in Spain (Confalone et al. 2010). But winter hardiness is still a major issue as survival influences the grain yield; e. g. in a previous experiment in Austria, a limited winter survival resulted in no yield advantage of winter faba bean over spring faba bean (Neugschwandtner et al. 2015b).

Winter varieties compared to Alexia had significantly a by over two-thirds higher stem density, by a three-quarter more stems plant⁻¹ (Figure 2(P)), more grains pod⁻¹ (Figure 2(R); n. s. for Hiverna in 2014/2015) and a higher TKW (Figure 3(H)) but less pods stem⁻¹ (Figure 3(B)). Also winter faba bean sown at different dates in autumn in Australia showed a higher grain yield with earlier sowing; Loss et al. (1997) attributed this to an earlier and longer flowering and higher values of leaf area index, radiation use efficiency and production of nodes, biomass and harvest index, while Adisarwanto and Knight (1997) point to higher pod density as the pod development period and the number of pod-bearing nodes on the main stems increased with earlier sowing.

By doubling the SR, the above-ground dry matter yield of Alexia could be increased by about a fourth

and that of Hiverna by about a tenth (Figure 2(A)). Also the grain yield of Alexia tended to be higher with the higher SR, a higher SR impaired the grain yield of Diva while Hiverna was not affected by SR (Figure 2(C)). The harvest index was not affected by SR (Figure 2(K)), whereas a lower harvest index with higher SR has been reported for faba bean by Adisarwanto and Knight (1997) and Loss et al. (1998) and for soybean by Neugschwandtner et al. (2019c). A higher SR of faba bean has been shown in Australia to result in an earlier canopy closure, more radiation absorption, a higher dry matter accumulation especially in early growth stages and in higher seed yields (Loss et al. 1998). However, the optimal SR of faba bean depends strongly on location and environment. For example, the grain yield of spring faba bean grown in Poland could be increased by raising SR from 20 to 40 and further to 80 plants m⁻² (Filek et al. 1997). In contrast, grain yield of winter faba bean grown in Spain increased from 10 to 16 plants m⁻², but not further with 21 plants m⁻² (Aguilera-Diaz and Recalde-Manrique 1995). But faba bean also has high crop plasticity in the formation of yield components, which is more evident in longer growing seasons and under optimal environmental conditions compared to suboptimal conditions and after late sowing, in which the yield responds positively to an increased plant density (López-Bellido et al. 2005). Adjusting SR is important for optimizing intraspecific plant competition for water, nutrients and sunlight (de Luca et al. 2014) as SR strongly affects phenotypic plasticity, the ability of plants to adjust to the variability of environmental factors. For example, SR × Y effects have been shown for soybean: strong intraspecific competition occurred with low plant densities, whereas under dry conditions, yield increase could be observed with increasing plant density (Klimek-Kopyra et al. 2021). We observed SR × V interactions: intraspecific competition with a higher SR was much higher for winter faba beans than for the spring faba bean.

The grain yield tended to be higher with higher SR for spring-sown Alexia (Figure 2(C)). Similar to that observation, Adisarwanto and Knight (1997) reported a seeding rate × sowing date interaction for winter faba bean grown in Australia, which showed higher yields with a higher SR for a later sowing in autumn. The location also affects ideal SR: results from 109 field trials of soybean from southern Brazil showed that the SR could be reduced in high-yielding compared to low-yielding environments without losing yields (Corassa et al. 2018).

The formation of yield components of all varieties was strongly influenced by SR, contrary to the area-related yields. The higher SR increased plant and stem density

by 82% or 38% (Figure 2(M,O)). But only stems plant⁻¹ of winter faba bean varieties were lower (Figure 2(Q)), indicating that an intraspecific competition between plants already occurred early in the year. As multiple stems are rare for spring faba bean (Geisler 1983), this crop characteristic was not affected by SR. A lower number of stems plant⁻¹ with a higher SR for winter but not for spring faba bean has already been reported by Pilbeam et al. (1991). Further, pods plant⁻¹ were lower with the higher SR for all three varieties (Figure 2(U)) and also pods stem⁻¹ of Alexia and Diva (Figure 2(W)), indicating a higher intraspecific competition during stem elongation, flowering and pod set. Therefore, just Alexia could achieve a higher pod density with 50 S compared to 25 S (Figure 2(Q)), which resulted in a higher grain yield. Loss and Siddique (1997) reported that the grain yield of faba bean was among yield components strongest correlated with pod density. Whereas TKW, which is the product of the individual seed growth rate and the effective seed-filling period (Van Roekel et al. 2015), was not affected by SR for all varieties (Figure 3(A)), indicating that SR did not alter the intraspecific competition in crop stands during the growth stage of fruit development.

Pilbeam et al. (1991) stated that several yield components are important for the crop plasticity of faba bean, which makes selecting for particular yield components for increasing the yield difficult. For winter faba bean, however, stems plant⁻¹ might be the most influential factor for achieving a high stem density, enabling therefore a lower SR (López-Bellido et al. 2005).

Pod density, which largely determines the variations of the grain yield (Adisarwanto and Knight 1997), was not affected by SR except for Alexia (Figure 2(S)) as also reported by Patrick and Stoddard (2010). SR affected pods plant⁻¹ and pods stem⁻¹ (Figure 2(U,W)) but no effect of SR on grains pod⁻¹ or TKW was observed (Figure 3(A,G)), as described also by Herzog and Geisler (1991), Adisarwanto and Knight (1997) and Loss et al. (1998), which is caused by stable genotypic rank orders for these traits (Herzog and Geisler 1991). Further, physiological stresses generally reduce pods plant⁻¹ rather than grains pod⁻¹ or TKW (Adisarwanto and Knight 1997). Grains pod⁻¹ are also relatively consistent over seeding dates (Loss and Siddique 1997). Similar to our observations, also soybean grown in the northeastern United States (Cox et al. 2010) and in Austria (Neugschwandtner et al. 2019c) attained the same grain yield and grain density with a lower SR than the recommended one as they compensated lower plant density with more pods plant⁻¹ and grains plant⁻¹, whereas grains pod⁻¹ and TKW again did not change. In competition with oat in oat-pea intercrops,

however, the TKW of pea decreased with a lower SR (Neugschwandtner and Kaul 2014).

On the single plant level, changes of the yield components grains plant⁻¹, grains stem⁻¹, grain yield plant⁻¹ and grain yield stem⁻¹ (Figure 3(C,F,K,M)) showed with different SR a similar pattern as the changes of pods plant⁻¹ and pods stem⁻¹ (Figure 2(U,W)), as TKW and grains pod⁻¹ (Figure 3(A,G)) were not affected by SR. A decrease of grains plant⁻¹ and grain yield plant⁻¹ with higher SR (Figure 3(C,K)) has already been reported for faba bean (Filek et al. 1997) and soybean (Neugschwandtner et al. 2019c). For soybean, grains pod⁻¹, TKW and the grain yield pod⁻¹ were also not affected. SR does not just affect yield and yield components of faba bean; with a higher SR, also the number and dry matter of nodules m⁻² were reported to increase, whereas the number and dry matter of root nodules plant⁻¹ decreased (Filek et al. 1997).

Conclusion

In conclusion, the grain yield of the spring faba bean could be improved with a higher seeding rate, whereas no yield difference was observed for winter faba beans. Obviously, the higher seeding rate caused detrimental intraspecific competition, reducing stems plant⁻¹ with a higher seeding rate. Also pods plant⁻¹ were lower with higher seeding rate for all three varieties, but more for the winter varieties. Results show that winter faba bean can be sown in Central Europe with lower SR compared to spring faba bean without suffering grain yield loss.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

- Adisarwanto T, Knight R. **1997**. Effect of sowing date and plant density on yield and yield components in the faba bean. *Aust J Agric Res.* 48:1161–1168.
- Aguilera-Diaz C, Recalde-Manrique L. **1995**. Effects of plant density and inorganic nitrogen fertilizer on field beans (*Vicia faba*). *J Agric Sci.* 125:87–93.
- Bodner G, Kronberga A, Lepse L, Olle M, Vågen IM, Rabante L, Fernández JA, Ntatsi G, Balliu A, Rewald B. **2018**. Trait identification of faba bean ideotypes for Northern European environments. *Eur J Agron.* 96:1–12.
- Brückler M, Resl T, Reindl A. **2017**. Comparison of organic and conventional crop yields in Austria. *Bodenkultur.* 68:223–236.
- Confalone A, Lizaso JL, Ruiz-Nogueira B, López-Cedrón F-X, Sau F. **2010**. Growth, PAR use efficiency, and yield components of field-grown *Vicia faba* L. under different temperature and photoperiod regimes. *Field Crops Res.* 115:140–148.
- Corassa GM, Amado TJC, Strieder ML, Schwalbert R, Pires JLF, Carter PR, Ciampitti IA. **2018**. Optimum soybean seeding rates by yield environment in southern Brazil. *Agron J.* 110:2430–2438.
- Cox WJ, Cherney JH, Shields E. **2010**. Soybeans compensate at low seeding rates but not at high thinning rates. *Agron J.* 102:1238–1243.
- de Luca MJ, Nogueira MA, Hungria M. **2014**. Feasibility of low-erger soybean planting density without compromising nitrogen fixation and yield. *Agron J.* 106:2118–2124.
- Filek W, Kościelniak J, Grzesiak S. **1997**. The effect of nitrogen fertilization and population density of the field bean (*Vicia faba* L. minor) of indeterminate and determinate growth habit on the symbiosis with root nodule bacteria and on the seed yield. *J Agron Crop Sci.* 179:171–177.
- Geisler G. **1983**. Ertragsphysiologie von Kulturarten des gemäßigten Klimas. Hamburg und Berlin: Paul Parey.
- Henseler M, Piot-Lepetit I, Ferrari E, Mellado AG, Banse M, Grethe H, Parisi C, Hélaine S. **2013**. On the asynchronous approvals of GM crops: potential market impacts of a trade disruption of EU soy imports. *Food Policy.* 41:166–176.
- Herzog H, Geisler G. **1991**. Yield structure of winter faba beans grown in northern Germany in dependence of different environments, seed rates, sowing dates and genotypes. *J Agron Crop Sci.* 167:145–154.
- Karcher DE, Richardson MD. **2005**. Batch analysis of digital images to evaluate turfgrass characteristics. *Crop Sci.* 45:1536–1539.
- Karkanis A, Ntatsi G, Lepse L, Fernández JA, Vågen IM, Rewald B, Alsina I, Kronberga A, Balliu A, Olle M, et al. **2018**. Faba bean cultivation – revealing novel managing practices for more sustainable and competitive European cropping systems. *Front Plant Sci.* 9:1115.
- Klima K, Wiśniowska-Kielian B. **2006**. Anti-erosion effectiveness of selected crops and the relation to leaf area index (LAI). *Plant Soil Environ.* 52:35–40.
- Klimek-Kopyra A, Baciór M, Lorenc-Kozik A, Neugschwandtner RW, Zając T. **2021**. Intraspecific competition as a driver for true production potential of soybean. *Ital J Agron.* 16:1709.
- Kulig B, Kołodziej J, Oleksy A, Kołodziejczyk M, Sajdak A. **2011**. Influence of the weather conditions on faba bean yielding. *Ecol Chem Eng.* 18:1–7.
- Kulig B, Oleksy A, Sajdak A. **2009**. Yielding of selected faba bean cultivars depending on plant protection methods and sowing density. *Fragm Agron.* 26:93–101.
- Link W, Balko C, Stoddard FL. **2010**. Winter hardiness in faba bean: Physiology and breeding. *Field Crops Res.* 115:287–296.
- Loss SP, Siddique KHM. **1997**. Adaptation of faba bean (*Vicia faba* L.) to dry land Mediterranean-type environments I. Seed yield and yield components. *Field Crops Res.* 52:17–28.
- Loss SP, Siddique KHM, Jettner R, Martin LD. **1998**. Responses of faba bean (*Vicia faba* L.) to sowing rate in southwestern Australia I. Seed yield and economic optimum plant density. *Aust J Agric Res.* 49:989–997.
- Loss SP, Siddique KHM, Martin LD. **1997**. Adaptation of faba bean to dryland Mediterranean-type environments. II. Phenology, canopy development, radiation absorption and biomass partitioning. *Field Crops Res.* 52:29–41.
- López-Bellido FJ, López-Bellido L, López-Bellido RJ. **2005**. Competition, growth and yield of faba bean (*Vicia faba* L.). *Eur J Agron.* 23:359–378.
- Mwanamwenge J, Loss S, Siddique K, Cocks P. **1999**. Effect of water stress during floral initiation, flowering and podding on the growth and yield of faba bean (*Vicia faba* L.). *Eur J Agron.* 11:1–11.
- Neugschwandtner RW, Bernhuber A, Kammlander S, Wagentristl H, Klimek-Kopyra A, Kaul H-P. **2019a**. Agronomic potential of winter grain legumes for Central Europe: Development, soil coverage and yields. *Field Crops Res.* 241:107576.
- Neugschwandtner RW, Bernhuber A, Kammlander S, Wagentristl H, Klimek-Kopyra A, Kaul H-P. **2020**. Yield structure components of autumn- and spring-sown pea (*Pisum sativum* L.). *Acta Agric Scand B Soil Plant Sci.* 70:109–116.
- Neugschwandtner RW, Bernhuber A, Kammlander S, Wagentristl H, Klimek-Kopyra A, Lošák T, Zholamanov KK, Kaul H-P. **2021**. Nitrogen yields and biological nitrogen fixation of winter grain legumes. *Agronomy.* 11:681.
- Neugschwandtner RW, Böhm K, Hall RM, Kaul H-P. **2015a**. Development, growth, and nitrogen use of autumn- and spring-sown facultative wheat. *Acta Agric Scand B Soil Plant Sci.* 65:6–13.
- Neugschwandtner RW, Kaul H-P. **2014**. Sowing ratio and N fertilization affect yield and yield components of oat and pea in intercrops. *Field Crops Res.* 155:159–163.
- Neugschwandtner RW, Papst S, Kemetter J, Wagentristl H, Sedlář O, Kaul H-P. **2019b**. Effect of seed size on soil cover, yield, yield components and nitrogen uptake of two-row malting barley. *Bodenkultur.* 70:89–98.

- Neugschwandtner RW, Wichmann S, Gimplinger DM, Wagentristsl H, Kaul H-P. **2013**. Chickpea performance compared to pea, barley and oat in Central Europe: growth analysis and yield. *Turkish J Field Crops*. 18:179–184.
- Neugschwandtner RW, Winkler J, Bernhart M, Pucher MA, Klug M, Werni C, Adam E, Kaul H-P. **2019c**. Effect of row spacing, seeding rate and nitrogen fertilization on yield and yield components of soybean. *Bodenkultur*. 70:221–236.
- Neugschwandtner RW, Ziegler KV, Kriegner S, Kaul H-P. **2015b**. Limited winter survival and compensation mechanisms of yield components constrain winter faba bean production in Central Europe. *Acta Agric Scand B Soil Plant Sci*. 65:496–505.
- Patrick JW, Stoddard FL. **2010**. Physiology of flowering and grain filling in faba bean. *Field Crops Res*. 115:234–242.
- Pilbeam CJ, Hebblethwaite PD, Ricketts HE, Nyongesa TE. **1991**. Effects of plant population density on determinate and indeterminate forms of winter field beans (*Vicia faba*). 1. Yield and yield components. *J Agric Sci*. 116:375–383.
- Reckling M, Döring TF, Bergkvist G, Stoddard FL, Watson CA, Seddig S, Chmielewski F-M, Bachinger J. **2018**. Grain legume yields are as stable as other spring crops in long-term experiments across Northern Europe. *Agron Sustain Dev*. 38:63.
- Richardson MD, Karcher DE, Purcell LC. **2001**. Quantifying turfgrass cover using digital image analysis. *Crop Sci*. 41:1884–1888.
- Robson MC, Fowler SM, Lampkin NH, Leifert C, Leitch M, Robinson D, Watson CA, Litterick AM. **2002**. The agronomic and economic potential of break crops for ley/arable rotations in temperate organic agriculture. *Adv Agron*. 77:369–427.
- Sauermann W. **2017**. Saatstärke optimieren – Erträge sichern. In: Boenisch A, van het Loo S, editors. *Ackerbohnen und Körnererbsen. Praxisnah - Sonderausgabe Leguminosen* 2017; p. 18–22.
- Shapbaugh WT, Wilcox JR. **1980**. Relationships between harvest index and other plant characteristics in soybeans. *Crop Sci*. 20:529–533.
- Stützel H, Aufhammer W. **1992**. Grain yield in determinate and indeterminate cultivars of *Vicia faba* with different plant distribution patterns and population densities. *J Agric Sci*. 118:343–352.
- van het Loo S, Sass O. **2017**. Die Winterackerbohne – züchertisch noch am Anfang. In: Boenisch A, van het Loo S, editor. *Ackerbohnen und Körnererbsen. praxisnah - Sonderausgabe Leguminosen* 2017; p. 11–13.
- Van Roekel RJ, Purcell LC, Salmerón M. **2015**. Physiological and management factors contributing to soybean potential yield. *Field Crops Res*. 182:86–97.
- Zander P, Amjath-Babu TS, Preissel S, Reckling M, Bues A, Schläfke N, Kuhlman T, Bachinger J, Uthes S, Stoddard F, et al. **2016**. Grain legume decline and potential recovery in European agriculture: a review. *Agron Sustain Dev*. 36:26.