Original Study • DOI: 10.15212/ijafr-2022-0024 IJAFR • 2022 • 1-13

Irish Journal of Agricultural and Food Research

# Yield response of field beans (*Vicia faba*) to plant population and sowing date in a temperate climate

L.C. Murphy[1,2†], D.L. Sparkes[2], J.H. Spink[1] and S. Alves[1]

[1]*Teagasc, Crops, Environment & Land Use Programme, Oak Park Crops Research Centre, Carlow, Ireland*
[2]*University of Nottingham, Sutton Bonington, Loughborough, LE12 5RD, UK*

**Abstract**

***Sowing date and seed rate influence crop establishment, growth, yield and profitability. The growth and yield of field beans (*Vicia faba*) in response to sowing date and seed rate was examined over three seasons, 2016–2019, in Teagasc, Oak Park, Carlow, Ireland. Early winter sowings (October) established better than late winter sowings in November and January. No significant difference was found in establishment from mid-February to mid-March. Yield was generally highest from October sowings for the winter cultivar. Yields were similar from February, March and April sowings for the spring cultivar, with March generally yielding higher across the three seasons. Yield was also found to increase significantly with seed rate for both winter and spring cultivars. The economic optimum plant population was estimated for the October and March sowing dates, by fitting a standard (linear + exponential) curve. There is no published information on the optimum plant populations for field beans in Ireland and we believe we are the first to report these findings. The estimated economic optimum plant populations varied between 13 and 38 plants/m$^2$ for both varieties, with an average optimum of 25.5 plants/m$^2$. This range falls within the current recommendations for sowing field beans in Ireland, demonstrating that increasing plant populations above the current commercial practice for field beans in Ireland, will not increase yield or profitability.***

**Keywords**

*economic optimum; establishment; field beans; plant populations; temperate climate; yield*

## Introduction

Field beans (*Vicia faba* L. var. minor) have the potential to produce high yields in temperate climates to supply home-grown protein for animal feed. However, this potentially valuable crop is not popular among growers because of its perceived year-on-year variability in comparison to cereals. However, in response to support for the crop by the introduction of the protein grant as part of the Common Agricultural Policy (CAP) greening scheme, field bean area in Ireland increased rapidly from 3,500 ha in 2014 to its highest of c.12,000 ha in 2017 (CSO, 2020).

Achieving an optimal canopy size is important for sufficient interception of radiation, and production of assimilates; however, too large a canopy can also lead to problems such as lodging and high disease pressure (Pilbeam *et al*., 1990; Loss *et al*., 1998b). Leguminous crops like field beans have the ability to fix their own nitrogen through a symbiosis with rhizobium bacteria (Hamdi, 1982). These rhizobium bacteria, found with nodules on the roots, saturate the soil with inorganic nitrogen compounds and in this way, they boost soil fertility naturally, allowing growers to save on synthetic fertilisers. Many studies have shown the importance of rhizobium bacteria on nitrogen fixation in legumes and their effect on soil fertility (Fatima *et al*., 2007; Mabrouk *et al*., 2018; Romanyà & Casals, 2020). Because field beans generally do not require mineral or nitrogenous fertiliser, the most efficient way to adjust the size of the crop canopy is through the seeding rate which, along with establishment, determines the number of plants per square metre. One of the main determinants of establishment is sowing date, as optimal conditions for germination and early plant development depend on the soil and air temperature.

Studies have shown that there are advantages to sowing higher plant populations. In soy beans, Robinson and Conley (2007) found that higher plant populations lead to quicker canopy closure. This results in early maximisation of light interception and less competition from weeds. However, having a higher plant population does not necessarily mean an increase in yield. Lower plant populations tend to produce

[†]Corresponding author: L.C. Murphy
E-mail: Leona.Murphy@teagasc.ie

more branches which allow each plant to produce more leaf area for light interception and to produce more pods per plant (Robinson & Conley, 2007). Higher plant densities can cause problems such as competition between plants for light, water and other nutrients (Pilbeam *et al*., 1991), as well as an increase in the risk of lodging.

Sowing date can have a profound influence upon the course of plant development. It has been observed in wheat that delaying sowing date for spring cereals causes an acceleration of crop development and results in lower maximum green area index (Hay & Walker, 1989). It has been repeatedly found that there is an interaction between sowing date and optimum plant populations (Kirby, 1969; Baldwin, 1980; Green *et al*., 1985; Adisarwanto & Knight, 1997; Spink *et al*., 2000), as at later sowing dates individual plants are less able to increase growth to compensate for reduced plant density.

It is not known, however, how Ireland's temperate maritime climate with relatively warm winters and cool springs and summers affect the bean crop's ability to compensate for reduced plant population density. Nor is it known in these conditions how sowing date affects the yield potential of the crop or its ability to compensate for reduced plant populations.

## Materials and methods

### *Agronomy*

Field experiments were carried out for three consecutive years in Teagasc, Oak Park, Carlow, Ireland, following oats in 2016, spring barley in 2017 and winter barley in 2018. Phosphorous (P) and potassium (K) were maintained on all sites following national guidelines on soil fertility (Teagasc, 2016). Soil organic matter ranged from 3.9% to 4.8% and pH ranged from 6.4 to 7.1.

For all field experiments, certified seed of winter variety (cv. Wizard), spring varieties cv. Fuego (2016 and 2017) and cv. Fanfare (2018) was used. The change in spring variety for the third year was due to unavailability of cv. Fuego. Germination rate was ≥85% for all seeds. Experimental areas were cultivated with a conventional plough and one pass power harrow system. Plots were sown using a Wintersteiger plot drill (Wintersteiger AG, Austria). The seed was drilled 7–10 cm deep. A prophylactic programme of chemicals, as presented in Table 1, was used to minimise weeds, pests and diseases throughout the season. A Lingo/Nirvana mix was used as a pre-emergence herbicide in 2016–2017 only, as Lingo was removed from the approved chemical list. Nirvana was used as a pre-emergence herbicide in trials at a higher rate in 2017–2019. The crop was also sprayed with a desiccant before harvest to aid ripening.

### *Bird damage control*

In 2017, netting was erected over the November-sown plots, and a bird scarer was also placed in the field. This was due to loss of November plots in the previous year to bird damage. Nets were also erected over February 2019 plots to deter bird attacks on the plots after damage was found. Nets were only erected over sowing dates that were most likely to be impacted by bird damage or had seen to be damaged in the previous years.

### *Experimental design*

The experiments were arranged in a randomised, incomplete split-split plot design with four replications. The main plot treatment was time of sowing (TOS), sub-plot treatment was variety and sub-sub-plot treatment was seed rate (SR). Plot size was 5 m × 24 m, which was split in half lengthways (2.5 m × 24 m); one side of the plot was used for destructive samples and the other side for combine yield. In the last season, due to field restrictions and shortage of seed, the field experiment was divided into two incomplete split-split-plot designs with four replications.

**Table 1:** Programme of chemicals used throughout the season on trials from 2016 to 2019

| Chemical type | Chemical name | Rate of application |
|---|---|---|
| Fertiliser | 0.10.20 | 180 kg/ha |
| Herbicide | Rosate | 3.0 L/ha |
| Pre-emergence herbicide | Lingo/Nirvana mix (2016–2017) | 1.5 L + 3.5 L/ha |
| | Nirvana (2017–2019) | 4.5 L/ha |
| Post-emergence herbicide | BasagranSG/Phase 11 | 1.6 kg + 1.0 L/ha |
| Fungicide | Signum | 0.6 kg/ha |
| Insecticide | Ninja | 75 mL/ha |
| | Aphox | 250 g/ha |
| Desiccant | Reglone | 3.0 L/ha |

Field experiments consisted of six sowing dates from October to April, five SRs between 10 and 80 seeds/m$^2$ and two varieties. The five SRs were only sown in October and March; at the remaining sowing dates only three SRs (20, 40 and 60 seeds/m$^2$) were sown. The spring variety was sown at all sowing dates, but the winter variety was only sown in October and November.

In the last season (2018–2019), two trials were sown, to reduce the size of the trial and hence variability for the comparison of the full range of SRs. The first trial comprised two sowing dates (October and March), two varieties (Wizard, sown in October only and Fuego, sown at both sowing dates) and five SRs (10–80 seeds/m$^2$). The second trial included the six sowing dates, two varieties (Wizard sown in October and November, and Fanfare sown in all sowing dates) and three SRs (20, 40 and 60 seeds/m$^2$) (Table 2).

### *Crop establishment and plant population*

Plant counts for crop establishment were taken at the second leaf stage of growth (GS12; BBCH scale, Lancashire *et al*. (1991)). Establishment was assessed by randomly throwing a 1 m$^2$ plastic hoop into the plot. Ten counts were taken throughout the plot and an average plant population and percentage establishment were calculated per plot.

### *Combine harvest*

Plots were harvested mid-September each year when the crop was dry, black and seed was hard using a plot combine (Deutz-Fahr, Germany). A minimum area of 52–57 m$^2$ was harvested from each plot. As plots were harvested, moisture and weight were recorded on an attached handheld computer (Allegro, Juniper Systems, Austria) with accompanying software (Field Research Software [FRS] for GrainGage, Juniper systems, Austria).

### *Meteorological data*

Meteorological data were taken from the onsite weather station in Oak Park, Carlow, Ireland. Rainfall (mm), temperature (°C) and solar radiation (mJ/m$^2$) were recorded over the three seasons in 2016–2019. Historical weather data were obtained from the Irish Meteorological Service, Met Éireann, for long-term monthly rainfall and temperature averages from 2007 to 2019.

### *Statistical analysis*

Analysis of variance (ANOVA) and regression analyses were carried out using the statistical software GenStat, version 20 (VSN International, Hemel Hempstead, United Kingdom) and Microsoft Excel, Office 365 (Microsoft Corporation, Redmond, WA, USA). ANOVA was carried out across the experiments in the first 2 yrs and the second experiment in the final year. Winter and spring varieties were compared by analysing the 20, 40 and 60 SR treatments for October and November sowings only. All sowing dates were compared using the 20, 40 and 60 SRs for the spring variety only. Where the full range of SRs were compared, the analysis was restricted to winter and spring varieties in the October sowing and spring cultivar for the March sowing from the first 2 yrs and experiment 1 in the final year.

### *Economic optimum plant population*

The economic optimum was estimated for the winter and spring varieties in the October sowing and spring cultivar for the March sowing date for the five SRs over the three seasons. A standard curve (linear + exponential) was fitted using GenStat version 20 (VSN International). Economic optimum populations were estimated at the highest point on the response curve. Assuming a return from the harvested grain of €170/t, a seed cost of €205/t (S. Phelan, Teagasc, personal communication), a mean seed weight of 0.63 g and

**Table 2:** Experimental design for each experimental year, 2016–2019

| Year | 2016–2017 (one trial) | 2017–2018 (one trial) | 2018–2019 (two trials) | |
|---|---|---|---|---|
| Experimental design | Incomplete split-split plot design | Incomplete split-split plot design | Incomplete split-split plot design | |
| Cultivars | Fuego<br>Wizard | Fuego<br>Wizard | Fuego<br>Wizard<br>(two sowing dates) | Fanfare<br>Wizard<br>(six sowing dates) |
| Seed rates | 20, 40, 60 seeds/m$^2$ (Nov, Jan, Feb, Apr) | 20, 40, 60 seeds/m$^2$ (Nov, Jan, Feb, Apr) | 10, 20, 40, 60, 80 seeds/m$^2$ (Oct, Mar) | 20, 40, 60 seeds/m$^2$ (Nov, Jan, Feb, Apr) |
| | 10, 20, 40, 60, 80 seeds/m$^2$ (Oct, Mar) | 10, 20, 40, 60, 80 seeds/m$^2$ (Oct, Mar) | | 10, 20, 40, 60, 80 seeds/m$^2$ (Oct, Mar) |

a 60% establishment rate were used to convert seed cost into the cost per plant; this was calculated using the following equation:

$$A + B(R^{**}X) + C^{*}X$$

where A, B, C and R are the estimates of the parameters and X is plant number.

## Results

### *Meteorological data*

Temperature and radiation for the 3 yrs showed a typical trend for the moist maritime climate of Ireland (Figure 1B,C) and typically followed the long-term average. However, large variations in rainfall were observed over the three seasons. In 2018, rainfall between May and September was much lower than the average, with the lowest of 5.2 mm in June 2018 compared to the 67.8 mm long-term average (2007–2019; Met Éireann (2019)) for the same month (Figure 1A).

### *Crop establishment*

Because crop establishment dictates the plant population density, which is known to be a major factor in the determination of yield, it was important to study how this parameter varied with year, sowing dates, SRs and variety. Averaged across sowing date (October–April), seed rate (20–60 seeds/m$^2$) and variety, overall establishment varied significantly between years with the highest establishment in 2017 of 71%, compared to 60% in 2018 and 47% in 2019 ($P < 0.001$).

For the spring variety, in 2017, October and March sowings established significantly better than the other sowing dates followed by April and November with January giving the poorest establishment. In 2018, October, February and March established best, followed by January. There were no establishment data taken for April in 2018, due to severe weed infestation in plots at early growth stages. In 2019, February and March had the highest establishment followed by April. All of the earlier sowings (November, December and January) had poor establishment (Figure 2A).

In the winter variety treatments, establishment varied with year ($P < 0.001$), sowing date ($P < 0.001$) and seed rate ($P = 0.009$), in the 20–60 seeds/m$^2$ range, with significant interactions found between year with sowing date ($P < 0.001$) as presented in Figure 2B. In 2017 and 2018, the October sowing established significantly better than the November sowing ($P < 0.001$). In 2019, the November sowing established higher than the October sowing (Figure 2B).

### *Yield*

There were large differences in yield between the three seasons with average yields across sowing dates and varieties of 6.2 t/ha, 1.7 t/ha and 4.7 t/ha for 2017, 2018 and 2019, respectively ($P < 0.001$). The impact of sowing date on yield across the three seasons and treatments can be seen in Figure 3. There were significant differences in yield between sowing dates, but the ranking changed between years ($P < 0.001$). For the spring variety, in 2017, the October sowing yielded the highest, followed by the November (netted), March and April sowings, with January and February yielding the lowest ($P < 0.001$). In 2018, yields were much lower than in 2017 or 2019, with the October sowing producing the greatest yield ($P < 0.001$). The January sowing date yielded less than February but there were no other significant differences. In 2019, February yielded the highest, followed by November and March, then October and January, with April giving the lowest yield in that year ($P < 0.001$, Figure 3A).

For the winter variety, there was a strong interaction between year and sowing date ($P < 0.001$). In 2017, there was no significant difference found in yield between the October and November sowing dates (Figure 3B). In 2018, the October-sown treatment yielded more than the November-sown treatment (Figure 3B). In 2019, the November-sown treatment yielded more than the October-sown (Figure 3B).

Yield increased significantly with seed rate between 20, 40 and 60 seeds/m$^2$ in the spring-sown treatments, with average values of 2.7 t/ha, 3.7 t/ha and 4.1 t/ha, respectively ($P < 0.001$). Yield also increased with seed rate in the winter-sown treatments, with average values of 4.5 t/ha, 5.3 t/ha and 5.9 t/ha for 20, 40 and 60 seeds/m$^2$, respectively. This was supported in the broader seed range of 10–80 seeds/m$^2$ sown in October and March, with average values of 3.5 t/ha, 4.3 t/ha, 5.3 t/ha, 5.8 t/ha and 5.9 t/ha. Average values for yield for each year, sowing date, seed rate and variety are presented in Supplementary Table 1.

### *Variation of plant population with seed rate*

As expected, plant population (plant/m$^2$) varied directly with the seed rate (seed/m$^2$); however, a large variation in the plant population from individual seed rates was achieved. Regression analysis using all data, with plant density as the dependent variable and seed rate as the independent variable, showed a linear relationship, with a slope of 0.60 ($P < 0.001$) and intercept not significantly different from zero, which explained 64% of the variation. Further grouping of the data by years showed comparable slopes of 0.74 and 0.63, for 2017 and 2018, respectively, while a much lower slope of 0.43 was observed in 2019 ($P < 0.001$). Grouping by years explained 73% of the variation in plant density with seed rate. Due to the large variation in establishment

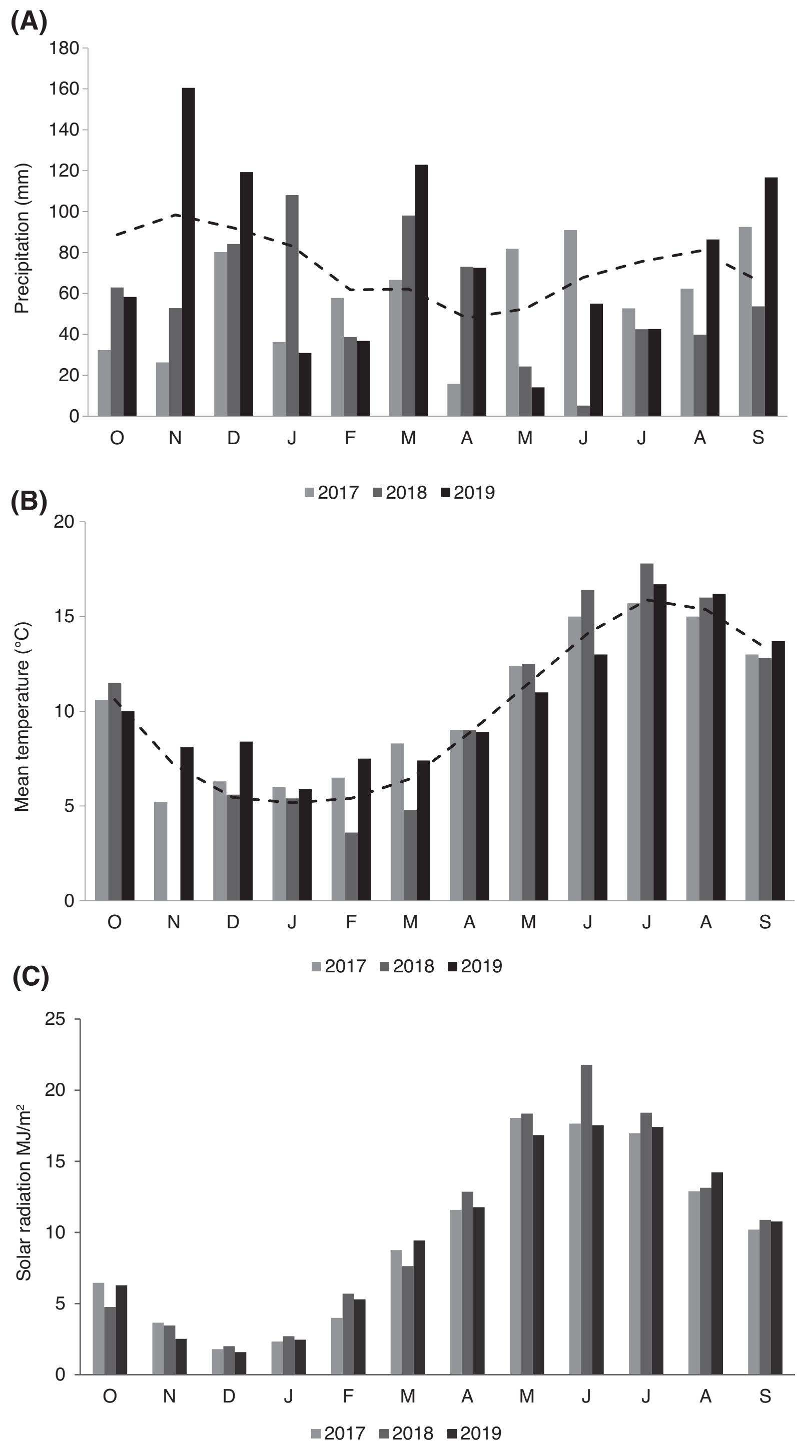


**Figure 1.** Meteorological data taken from the onsite weather station at Oak Park, Carlow showing (A) monthly accumulated rainfall (mm); (B) monthly mean temperature (°C); (C) mean daily solar radiation (MJ/m$^2$) from October to September across three seasons 2017–2019. The dashed line shows monthly average from 2007 to 2019 (Met Éireann, 2019).

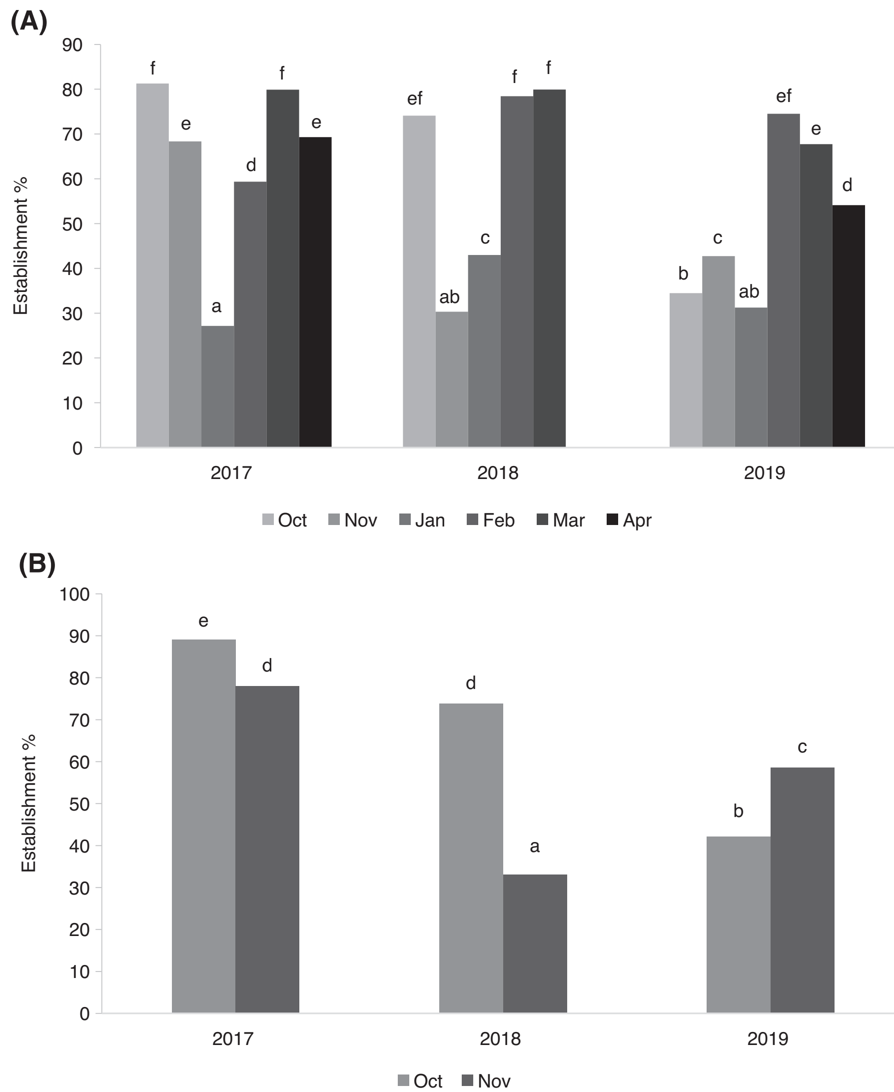


**Figure 2.** Average crop establishment of (A) spring variety (cv. Fuego/Fanfare) treatments sown in October, November, January, February, March and April (l-r) and (B) winter variety treatments (cv. Wizard) sown in October and November over three seasons 2017–2019. Different letters represent significant differences (at 5.0%) between treatments using Fisher's unprotected least significant difference multiple comparison test.

between years, sowing dates and seed rates, actual plant populations were used in the subsequent analysis rather than seed rate.

### *Economic optimum plant population*

The relationship between plant population density and yield for the October winter and spring varieties and the March spring variety showed that generally as plant population increased, yield increased (Figure 4) until 20 plants/m$^2$ for the October spring variety and 40 plants/m$^2$ for the March spring variety with no significant difference found ($P > 0.001$).

Fitted linear plus exponential curves for the winter and spring cultivar sown in October and the spring cultivar sown in March over the three seasons are given in Figure 5.

In 2017, the March-sown Fuego gave an economic optimum plant population of 38 plants/m$^2$, and the October-sown Fuego gave an optimum of 24 plants/m$^2$. For the October-sown Wizard, there was no increase in margin across the five seed rates and therefore no optimum could be calculated (Figure 5A). In 2018, due to extreme drought conditions which caused the crop to senesce earlier than expected, the economic optimum was found to be lower than the lowest plant population in the experiment (Figure 5B). In 2019, the

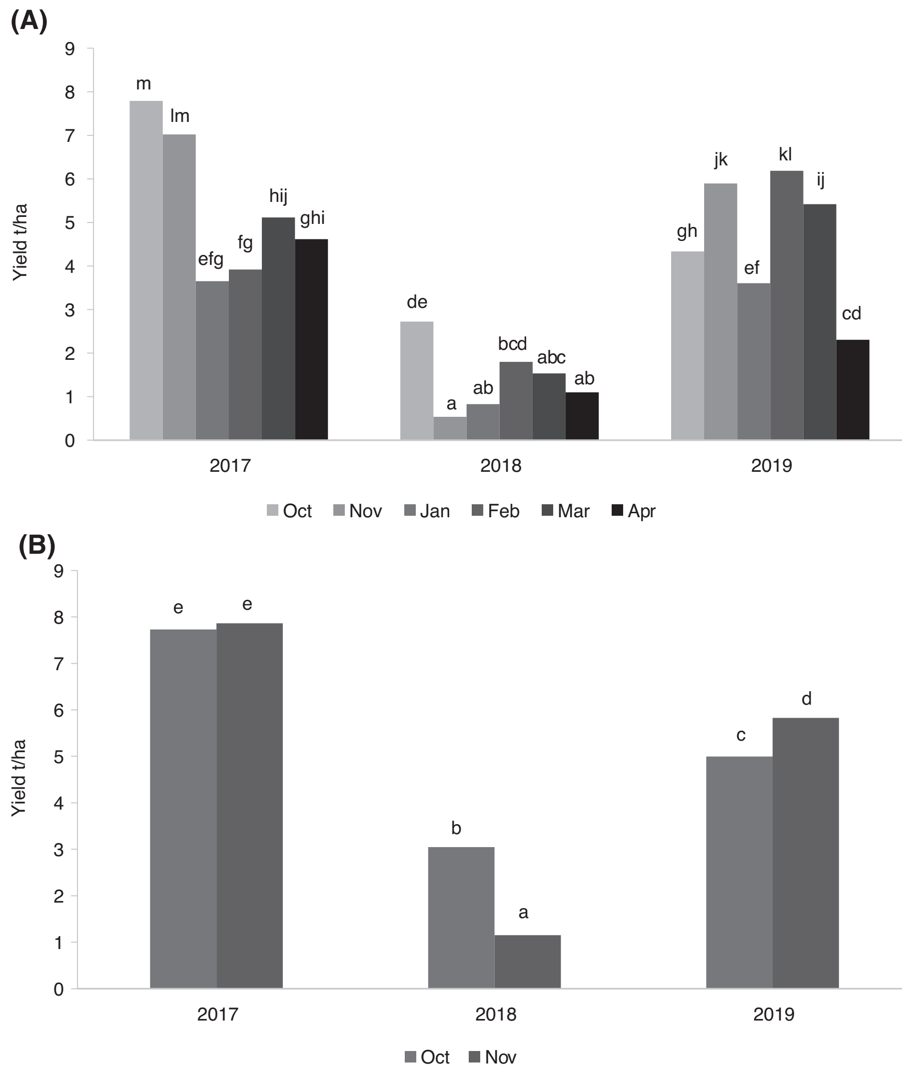


**Figure 3.** Average yield of (A) October, November, January, February, March and April sowings (l-r) for the spring variety (Fuego/Fanfare) and (B) winter-sown treatments in October and November for the winter variety (Wizard) over three seasons 2017–2019 at 15% moisture. Different letters represent significant differences (at 5.0%) between treatments using Fisher's unprotected least significant difference multiple comparison test.

March-sown Fuego gave an optimum plant population of 27 plants/m$^2$, the October-sown Fuego gave an optimum plant population of 31 plants/m$^2$ and the October Wizard gave an optimum plant population of 13 plants/m$^2$ (Figure 5C).

Overall, there was good consistency between years for each variety/sowing date combination, excluding the 2018 season. March- and October (cv. Fuego)-sown plots resulted in an optimum of 27–38 plants/m$^2$ and 24–31 plants/m$^2$, respectively, giving an overall range of 24–38 for the spring variety across years. Wizard-sown plots gave an economic optimum population of 13 plants/m$^2$ in 2019 and could not be calculated in 2017 due to a flat response. This effectively means that the lowest plant population density (PPD) of 10 plants/m$^2$ was the most cost-effective that year.

## Discussion

In Ireland, it is recommended to sow winter beans from the second week of October to mid-November and spring beans from the end of February to the end of March (Teagasc, 2017). However, growers might sow later in winter or earlier/later in

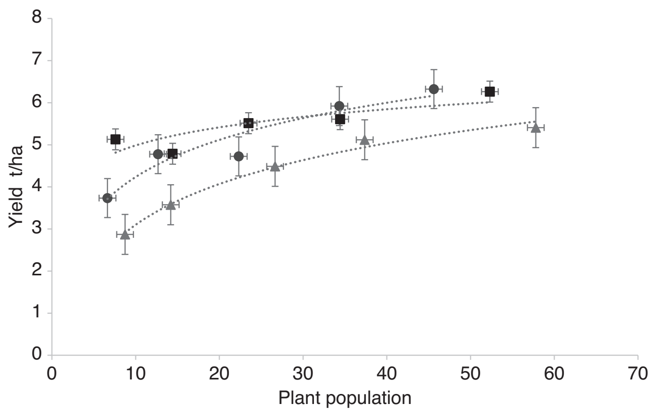


**Figure 4.** Relationship between plant population and yield, averaged across seed rates and years, 2017–2019, for October Fuego (●), October Wizard (■) and March Fuego (▲). Error bars show standard error of means.

spring depending on sowing conditions, with the knowledge that early-sown crops are more susceptible to bird damage and high disease pressure.

The consistently poor establishment in late winter and early spring sowings was related to environmental conditions such as bird damage, poor ground conditions and colder weather. Loss *et al*. (1998a) attributes poor establishment to physical damage to the seed caused by harvest, cleaning and mechanical sowing. There was no difference in establishment between sowing in October and November in 2017 but the October sowing established significantly better in 2018. Late winter sowings were negatively impacted by poor ground conditions and bird attacks. Sowing in March generally gave better establishment rates for spring varieties, with February and April sowings giving inconsistent results which varied year to year. Variability in establishment could have been due to a number of factors such as water availability, seed quality, soil type and environmental conditions.

Bird damage was clearly seen when comparing establishment in plots sown in November 2017, 2018 and 2019. The 2017 November-sown plots, which were netted, gave establishment values of 73% compared to 32% in 2018 and 51% in 2019 when the plots were not netted. In January, combined effects of wet conditions and/or bird damage resulted in establishment values below 43%. Poor establishment in April-sown plots in 2018 and 2019 may be related with wet conditions at sowing as well as weed growth in the plots during early crop growth.

Previous studies have found that sowing date has a significant influence on biomass production, grain yield and yield components (Confalone *et al*., 2010). The six sowing dates across the three seasons provided a wide range of environmental conditions for the performance of the crop which was found to be a contributing factor for the final crop yield. Field bean yield was poorest in 2018 when there was lower-than-average precipitation from pre-flowering to harvest. Yield in this study averaged 1.7 t/ha in 2018 compared to 6.2 t/ha in 2017 and 4.7 t/ha in 2019. The hot, dry conditions in 2018 accelerated the flowering period and stunted crop growth, with the crop receiving 111.8 mm of rainfall over this growth period compared to the long-term average of 276.7 mm. This was most notably detrimental in June 2018, during the crop's flowering period, when the crop received 5.2 mm of rain compared to the 67.8 mm long-term average for the month of June.

In 2017, the netted November-sown plots had comparable yields with the October-sown plots, as there was less bird damage. In 2018, October-sown plots yielded significantly more than those sown in November. February, March and April gave comparable yields, with March generally yielding the highest for the spring-sown treatments across the 3 yrs. January typically gave the worst conditions for sowing with poor ground conditions resulting in very damp, large aggregated soil after ploughing, making it difficult to reach the required seed depth of 7–10 cm. These results suggest that early winter and late spring sowings give the best yields. The advice from the Department of Agriculture, Food and Marine (DAFM) is in agreement with the results presented, but it is important to have the correct conditions for sowing and control bird damage in later winter sowings. For spring sowing, there is a wide window from February to April, with good ground conditions for ploughing and sowing probably being more important than the actual sowing date. This can be backed up by several studies showing the effect of sowing date on field beans in different countries. McVetty *et al*. (1986) found that in Western Canada, sowing date was a more important factor than SR in affecting final yield. Other parts of Europe, such as France, recommended an early sowing in spring to avoid water stress and high temperatures during the flowering period and pod setting (Berthelem, 1980), whereas in southern Italy, with a much warmer, semi-arid climate, an autumn sowing is preferred to a spring sowing, allowing a longer growing season and better utilisation of water, often resulting in higher yields (Ziliotto & Toniolo, 1979).

A key component of yield is the number of plants/m$^2$ (López-Bellido *et al*., 2005). Considering the variation in crop establishment over the 3 yrs, yield was examined against plant populations instead of SR. There were significant interactions found between plant populations with year, variety and sowing date. The general trend showed that as plant populations increased, yield increased. The exception for this was found in 2017 for the winter variety when no significant difference was found in yield with plant populations ranging from 12 to 57 plants/m$^2$. This agrees with previous work (Sprent *et al*., 1977; Pilbeam *et al*., 1991; Robinson & Conley, 2007), which reported that at low plant populations,

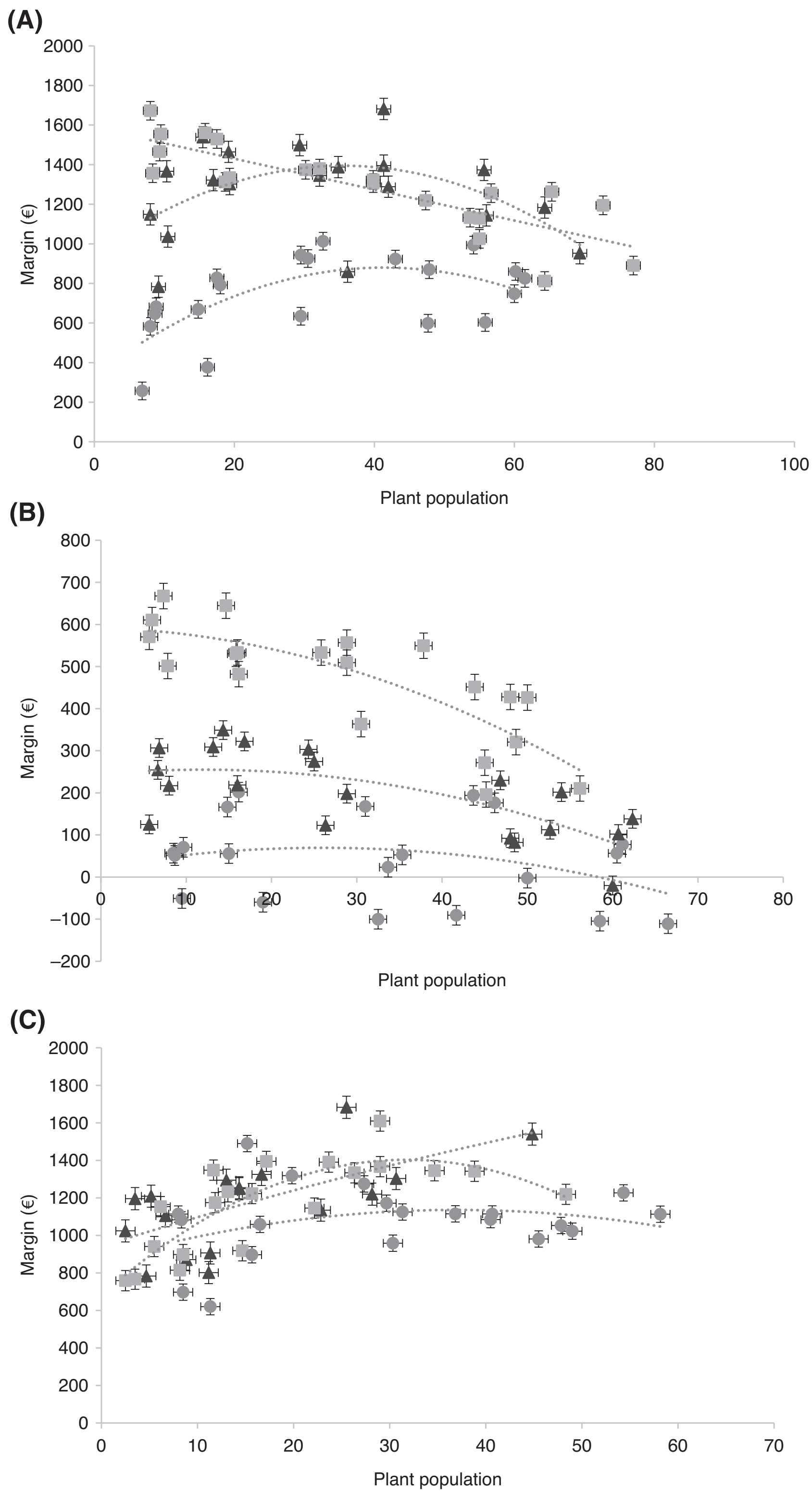


**Figure 5.** Linear + exponential curve fitting between gross profit margin (€/plant/m$^2$) and plant populations (plants/m$^2$) for October Fuego (▲), October Wizard (■) and March Fuego (●), across five seed rates for (A) 2017, (B) 2018 and (C) 2019 season. Error bars show standard error of means.

yield can be maintained as the crop is able to compensate through physiological processes such as branching and increased leaf area per plant. The variation in yield response to sowing date between years could be due, at least in part, to variation in crop establishment with the same SR achieving different plant densities each year.

As far as we are aware, this is the first study to examine the effect of plant populations on profitability of field bean production in Ireland. Although the estimated economic optimum plant population varied across the three seasons, from 24–38 plants/m$^2$ in 2017 to 28–31 plants/m$^2$ in 2019 for the spring variety and 13 plants/m$^2$ in 2019 for the winter variety, the current study shows that the yield and profits of field bean crops in Ireland will not improve by increasing SR. The results from this study show that the estimated economic optimum for the spring variety generally falls in the recommended range of 25–30 plants, taking into account 25–37.5% field losses after sowing (DAFM, 2020), suggesting that sowing higher than the recommended 40 seeds/m$^2$ for spring beans will not increase yields or profits for field bean crops. For the winter variety, however, the optimum of 13 plants/m$^2$ or less falls below the recommendations, suggesting that there may be an opportunity to lower plant populations in winter sowings, resulting in lower seed costs for growers. In contrast to this, in Australia studies by Loss *et al*. (1998a) found a mean economic optimum plant population of 45 plants/m$^2$. This indicates that in Ireland's temperate maritime climate the crop is better able to compensate for lower plant populations, presumably due to cooler conditions in Ireland providing more time for compensatory growth. However, optimum cropping regimes need to be tailored according to the farm and pedoclimate, to integrate the combined effects of the soil's temperature, water content and aeration. Crop densities will vary across soil types and this needs to be considered from a yield and profitability aspect. Free draining, sandy soils would generally have lower yields than that of heavier loamy soils (Teagasc, 2016). Farming equipment and cropping regimes can also influence crop densities and yield. Conservation agriculture, such as min-till or direct drill, has been promising in closing the yield gap and should be taken into consideration for the future.

In conclusion, field bean yields were found to be variable from year to year due to environmental factors throughout crop growth and development, with low water availability being the most detrimental to growth and final yield as seen in the 2018 season. With October generally yielding highest for the winter-sown treatments and February/March, for the spring-sown treatments, it is recommended to aim for these sowing dates when planting field beans in Ireland. The economic optimum plant populations after field losses for spring beans range from 24 to 38 plants/m$^2$, and 13 plants/m$^2$ or less for winter beans. This coincides with the current recommendations from the DAFM, to sow 40 seeds/m$^2$ to achieve 25–30 plants/m$^2$, but there may be an opportunity to reduce the plant population of winter beans without affecting final yield and profits. This study confirms that in Ireland, there is no benefit to sowing higher plant populations than currently recommended, as no profit is gained from higher sowing rates; indeed, it may be possible to improve profitability of winter-sown crops by reducing SR with no negative impact on yield; however, caution must be taken when reducing seed rates. Growers should take into consideration sowing date, soil type, ground conditions at sowing and lower establishment rates before considering lower seed rates.

## Acknowledgements

This work was supported by the Walsh Scholars Association and the Irish Farmers Association. The authors would like to acknowledge the Teagasc farm manager, farm staff, technicians and summer interns for their help in this study. Particular thanks to Kevin Murphy and Frank Ryan for their constant help and support throughout the entirety of this project.

## References

Adisarwanto, T. and R. Knight. 1997. Effect of sowing date and plant density on yield and yield components in the faba bean. *Australian Journal of Agricultural Research* **48**: 1161–1168.

Baldwin, B. 1980. Time of sowing-a major factor influencing the yields of *Vicia faba* in South Australia. *FABIS Newsletter*.

Berthelem, P. 1980. The major agronomic problems of the cultivation of faba bean (*Vicia faba* L.) in France. *FABIS Newsletter (ICARDA)*.

Confalone, A., Lizaso, J.I., Ruiz-Nogueira, B., López-Cedrón, F.X. and Sau, F. 2010. Growth, PAR use efficiency, and yield components of field-grown *Vicia faba* L. under different temperature and photoperiod regimes. *Field Crops Research* **115**: 140–148.

CSO 2020. "Area, Yield and Production of Crops." https://www.cso.ie/en/releasesandpublications/er/aypc/areayieldandproductionofcrops2020/ [Accessed 09 September 2020].

DAFM 2020. "Field Beans Recommended List 2020." Available online: https://www.gov.ie/en/publication/1ae65-spring-bean-recommended-list-2020/. [Accessed 20 August 2020].

Fatima, Z., Fatima, Z., Zia, M. and Chaudhary, F.M. 2007. Interactive effect of Rhizobium strains and P on soybean yield, nitrogen fixation and soil fertility. *Pakistan Journal of Botany* **39**: 255.

Green, C.F., Paulson, G.A. and Ivins, J.D. 1985. Time of sowing and the development of winter wheat. *The Journal of Agricultural Science* **105**: 217–221.

Hamdi, Y.A. 1982. Application of nitrogen-fixing systems in soil improvement and management (No. 49). Food & Agriculture Org.

Hay, R.K.M. and Walker, A.J. 1989. An Introduction to the Physiology of Crop Yield. Longman, Harlow.

Kirby, E. 1969. The effect of sowing date and plant density on barley. *Annals of Applied Biology* **63**: 513–521.

Lancashire, P.D., Lancashire, P.D., Bleiholder, H., Van den boom, T., Langelüddeke, P., Stauss, R. and Witzenberger, E.W.A. 1991. A uniform decimal code for growth stages of crops and weeds. *Annals of Applied Biology* **119**: 561–601.

López-Bellido, F.J., López-Bellido, L. and López-Bellido, R.J. 2005. Competition, growth and yield of faba bean (*Vicia faba* L.). *European Journal of Agronomy* **23**: 359–378.

Loss, S., Siddique, K.H.M., Jettner, R. and Martin, L.D. 1998a. Responses of faba bean (*Vicia faba* L.) to sowing rate in south-western Australia I. Seed yield and economic optimum plant density. *Australian Journal of Agricultural Research* **49**: 989–997.

Loss, S., Siddique, K.H.M., Crombie, A. and Martin, L.D. 1998b. Responses of faba bean (*Vicia faba* L.) to sowing rate in south-western Australia II. Canopy development, radiation absorption and dry matter partitioning. *Australian Journal of Agricultural Research* **49**: 999–1008.

Mabrouk, Y., Hemissi, I., Salem, I.B., Mejri, S., Saidi, M. and Belhadj, O. 2018. Potential of rhizobia in improving nitrogen fixation and yields of legumes. *Symbiosis* **107**: 73495.

McVetty, P.B.E., Evans, L.E. and Nugent-rigby, J. 1986. Response of faba bean (*Vicia faba* L.) to seeding date and seeding rate. *Canadian Journal of Plant Science* **66**: 39–44.

Met Éireann. 2019. “Met Éireann Historical Data.” 2019, Available online: https://www.met.ie/climate/available-data/historical-data.

Pilbeam, C.J., Duc, G. and Hebblethwaite, P.D. 1990. Effects of plant population density on spring-sown field beans (*Vicia faba*) with different growth habits. *The Journal of Agricultural Science* **114**: 19–33.

Pilbeam, C.J., Hebblethwaite, P.D., Nyongesa, T.E. and Ricketts, H.E. 1991. Effects of plant population density on determinate and indeterminate forms of winter field beans (*Vicia faba*) 2. Growth and development. *The Journal of Agricultural Science* **116**: 385–393.

Robinson, A.P. and Conley, S.P. 2007. Plant populations and seeding rates for soybeans. Available online: https://www.extension.purdue.edu/extmedia/ay/ay-217-w.pdf, Purdue Univ., West Lafayette, IN.

Romanyà, J. and Casals, P. 2020. Biological nitrogen fixation response to soil fertility is species-dependent in annual legumes. *Journal of Soil Science and Plant Nutrition* **20**: 546–556.

Spink, J.H., Semere, T., Sparkes, D.L., Whaley, J.M., Foulkes, M.J., Clare, R.W. and Scott, R. 2000. Effect of sowing date on the optimum plant density of winter wheat. *Annals of Applied Biology* **137**: 179–188.

Sprent, J.I., Bradford, A.M. and Norton, C. 1977. Seasonal growth patterns in field beans (*Vicia faba*) as affected by population density, shading and its relationship with soil moisture. *The Journal of Agricultural Science* **88**: 293–301.

Teagasc 2016. “Major and Micro Nutrient Advice for Productive Agricultural Crops”. Johnstown Castle, Enviromental Research Centre, Co. Wexford.

Teagasc 2017. “Field Beans.” Available online: https://www.teagasc.ie/crops/crops/research/programme-activities/cropquest/field-beans/ [Accessed 05 August 2020].

Ziliotto, U. and Toniolo, L. 1979. “Field trials on time of sowing field beans (*Vicia faba* var. minor) and broadbeans (*Vicia faba* var. major) at Padova in 1976 and 1977.” Some current research on *Vicia faba* in Western Europe, edited by DA Bond, GT Scarascia-Mugnozza and MH Poulsen; sponsored by the Commission of the European Communities, Directorate-General for Agriculture, Coordination of Agricultural Research.

## Supplementary material

**Supplementary Table 1:** Average yield for sowing dates, seed rates and varieties for three seasons 2017, 2018 and 2019.

| Harvest Year | Sowing date | Seed rate | Variety | Average yield |
|---|---|---|---|---|
| 2017 | Apr | 20 | Fuego | 3.85 |
| 2017 | Apr | 40 | Fuego | 4.64 |
| 2017 | Apr | 60 | Fuego | 5.36 |
| 2017 | Feb | 20 | Fuego | 3.32 |
| 2017 | Feb | 40 | Fuego | 4.07 |
| 2017 | Feb | 60 | Fuego | 4.70 |
| 2017 | Jan | 20 | Fuego | 2.43 |
| 2017 | Jan | 40 | Fuego | 3.86 |
| 2017 | Jan | 60 | Fuego | 4.65 |
| 2017 | Mar | 10 | Fuego | 2.96 |
| 2017 | Mar | 20 | Fuego | 3.89 |
| 2017 | Mar | 40 | Fuego | 5.46 |
| 2017 | Mar | 60 | Fuego | 5.98 |
| 2017 | Mar | 80 | Fuego | 5.98 |
| 2017 | Nov | 20 | Fuego | 6.16 |
| 2017 | Nov | 40 | Fuego | 7.50 |
| 2017 | Nov | 60 | Fuego | 7.40 |
| 2017 | Oct | 10 | Fuego | 5.65 |
| 2017 | Oct | 20 | Fuego | 7.54 |
| 2017 | Oct | 40 | Fuego | 7.48 |
| 2017 | Oct | 60 | Fuego | 8.35 |
| 2017 | Oct | 80 | Fuego | 8.32 |
| 2018 | Feb | 20 | Fuego | 1.08 |
| 2018 | Feb | 40 | Fuego | 1.72 |
| 2018 | Feb | 60 | Fuego | 2.49 |
| 2018 | Jan | 20 | Fuego | 0.51 |
| 2018 | Jan | 40 | Fuego | 0.73 |
| 2018 | Jan | 60 | Fuego | 1.13 |
| 2018 | Mar | 10 | Fuego | 0.64 |
| 2018 | Mar | 20 | Fuego | 1.07 |
| 2018 | Mar | 40 | Fuego | 1.45 |
| 2018 | Mar | 60 | Fuego | 2.09 |
| 2018 | Mar | 80 | Fuego | 2.28 |
| 2018 | Nov | 20 | Fuego | 0.13 |
| 2018 | Nov | 40 | Fuego | 0.51 |
| 2018 | Nov | 60 | Fuego | 0.56 |
| 2018 | Oct | 10 | Fuego | 1.36 |
| 2018 | Oct | 20 | Fuego | 3.27 |

**Supplementary Table 1:** Continued

| Harvest Year | Sowing date | Seed rate | Variety | Average yield |
|---|---|---|---|---|
| 2018 | Oct | 40 | Fuego | 2.10 |
| 2018 | Oct | 60 | Fuego | 3.44 |
| 2018 | Oct | 80 | Fuego | 2.79 |
| 2019 | Mar | 10 | Fuego | 5.02 |
| 2019 | Mar | 20 | Fuego | 5.17 |
| 2019 | Mar | 40 | Fuego | 6.10 |
| 2019 | Mar | 60 | Fuego | 7.33 |
| 2019 | Mar | 80 | Fuego | 7.96 |
| 2019 | Oct | 10 | Fuego | 4.19 |
| 2019 | Oct | 20 | Fuego | 5.82 |
| 2019 | Oct | 40 | Fuego | 6.52 |
| 2019 | Oct | 60 | Fuego | 7.68 |
| 2019 | Oct | 80 | Fuego | 7.86 |
| 2019 | Apr | 20 | Fanfare | 1.87 |
| 2019 | Apr | 40 | Fanfare | 2.53 |
| 2019 | Apr | 60 | Fanfare | 2.52 |
| 2019 | Feb | 20 | Fanfare | 5.54 |
| 2019 | Feb | 40 | Fanfare | 6.38 |
| 2019 | Feb | 60 | Fanfare | 6.62 |
| 2019 | Jan | 20 | Fanfare | 2.35 |
| 2019 | Jan | 40 | Fanfare | 3.58 |
| 2019 | Jan | 60 | Fanfare | 4.57 |
| 2019 | Mar | 20 | Fanfare | 4.18 |
| 2019 | Mar | 40 | Fanfare | 4.93 |
| 2019 | Mar | 60 | Fanfare | 5.08 |
| 2019 | Nov | 20 | Fanfare | 4.11 |
| 2019 | Nov | 40 | Fanfare | 6.84 |
| 2019 | Nov | 60 | Fanfare | 6.70 |
| 2019 | Oct | 20 | Fanfare | 2.47 |
| 2019 | Oct | 40 | Fanfare | 2.79 |
| 2019 | Oct | 60 | Fanfare | 4.21 |
| 2017 | Nov | 20 | Wizard | 7.90 |
| 2017 | Nov | 40 | Wizard | 7.71 |
| 2017 | Nov | 60 | Wizard | 7.96 |
| 2017 | Oct | 10 | Wizard | 7.63 |
| 2017 | Oct | 20 | Wizard | 7.63 |
| 2017 | Oct | 40 | Wizard | 7.73 |
| 2017 | Oct | 60 | Wizard | 7.82 |
| 2017 | Oct | 80 | Wizard | 7.76 |

**Supplementary Table 1:** Continued

| Harvest Year | Sowing date | Seed rate | Variety | Average yield |
|---|---|---|---|---|
| 2018 | Nov | 20 | Wizard | 1.08 |
| 2018 | Nov | 40 | Wizard | 0.67 |
| 2018 | Nov | 60 | Wizard | 1.47 |
| 2018 | Oct | 10 | Wizard | 3.12 |
| 2018 | Oct | 20 | Wizard | 2.04 |
| 2018 | Oct | 40 | Wizard | 3.49 |
| 2018 | Oct | 60 | Wizard | 2.51 |
| 2018 | Oct | 80 | Wizard | 3.64 |
| 2019 | Oct | 10 | Wizard | 4.63 |
| 2019 | Oct | 20 | Wizard | 6.45 |
| 2019 | Oct | 40 | Wizard | 6.66 |
| 2019 | Oct | 60 | Wizard | 6.81 |
| 2019 | Oct | 80 | Wizard | 7.40 |
| 2019 | Oct | 20 | Wizard | 3.03 |
| 2019 | Oct | 40 | Wizard | 4.17 |
| 2019 | Oct | 60 | Wizard | 5.30 |
| 2019 | Nov | 20 | Wizard | 4.98 |
| 2019 | Nov | 40 | Wizard | 5.64 |
| 2019 | Nov | 60 | Wizard | 6.82 |