The Journal of Agricultural Science

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Effect of three crop rotations and four residue levels on canola and bean grain yield and residue production

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Crops and Soils Research Paper

Cite this article: Hirzel J, Undurraga P, León L, Matus I (2023). Effect of three crop rotations and four residue levels on canola and bean grain yield and residue production. *The Journal of Agricultural Science* **161**, 272–278. https://doi.org/10.1017/S0021859623000163

Received: 5 July 2022
Revised: 31 October 2022
Accepted: 13 February 2023
First published online: 17 February 2023

Keywords:
Conservation agriculture; crop production; recycling of nutrients

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Abstract

Crop rotation in agriculture can lead to increased crop productivity in the rotation and improved soil fertility as a result of residue incorporation. Unfortunately, residue incorporation is not a common practice in crop production systems under the Mediterranean regime, largely due to the lack of information on the effect of the follow-up crops. Therefore, this study was conducted with six biannual rotations (bread wheat–canola, bread wheat–bean, durum wheat–canola, durum wheat–bean, corn–canola and corn–bean) using four residue incorporation levels (0, 50, 100 and 200%) in an Andisol in south central Chile. Grain yield and residue production were evaluated in the canola and bean crops 5 years after initiating crop rotation. The previous crop affected canola grain yield and residue production, which were both higher after corn. Meanwhile, the residue incorporation level had a slight effect on residue production after bread wheat. Only bean grain yield was affected by the previous crop, which was higher after the durum wheat and corn crops. The residue incorporation has marginally affected residue production after bread wheat. Finally, residue incorporation at different levels under the conditions of the present experiment had a minimal effect on bean and canola residue production following the bread wheat crop. The best crop rotation for canola grain yield was corn–canola, which produced 0.54 Mg/ha (18.3%) higher yield than the average of the other two rotations. The best crop rotation for achieving higher bean grain yield was corn–bean, which yielded 0.52 Mg/ha (12.3%) higher than the average of the other two rotations.

Introduction

Crop rotation in agriculture maintains and improves soil fertility, interrupts disease cycles, controls pathogens and weeds (Melander *et al.*, 2020; Passaris *et al.*, 2021; Sietz *et al.*, 2021), and increases the yield of each crop in the rotation cycle (Fang *et al.*, 2021; Sainju *et al.*, 2021). Crop rotation also promotes soil water conservation, reduces erosion, maintains biodiversity, enables the incorporation of sustainable management practices (Grahmann *et al.*, 2020; Sietz *et al.*, 2021), increases energy use efficiency (Khakbazan *et al.*, 2019) and fertilizer use efficiency (Basso *et al.*, 2019; Taveira *et al.*, 2020). In contrast, it has been reported that the corn (*Zea mays* L.) monocrop increased soil acidity and promoted the development of fungi, ammonia oxidizing bacteria and nirK-denitrifier groups (Behnke *et al.*, 2020). Some authors have mentioned lower yields in a corn monocrop compared with the same crop in different rotations (Huynh *et al.*, 2019; Scott *et al.*, 2021). When legume crops are included in crop rotations, the N contribution is increased to non-legume crops such as wheat (*Triticum aestivum* L.), canola (*Brassica napus* L.) (Angus *et al.*, 2015; Peoples *et al.*, 2017) and corn (Huynh *et al.*, 2019). This is also corroborated by a higher yield in the durum wheat (*Triticum turgidum* L.) crop in a rotation following a bean (*Phaseolus vulgaris* L.) crop compared with a canola crop (Hirzel *et al.*, 2021b, 2021d). Some authors have indicated that legume crops in crop rotations provided the equivalent of 75 kg/ha N to the wheat crop and that this effect can last beyond one growing season (Mingotte *et al.*, 2021). The benefits of legumes in crop rotations have also been mentioned in studies conducted in south-eastern Australia (Song *et al.*, 2021).

Residue incorporation increases soil fertility, mainly through organic carbon (C) gain, reduces greenhouse gas emissions, increases aggregate stability and improves gas exchange and nutrient and water cycling in the soil (Lal, 2016; Khakbazan *et al.*, 2019; Yang *et al.*, 2019; Behnke *et al.*, 2020). The incorporation of bread wheat and canola crop residues in different crop rotations or under wheat monocropping conditions stimulated the mineralization of soil organic matter and increased phosphorus (P) and sulphur (S) concentrations in two soils in New South Wales, Australia (Sarker *et al.*, 2019). However, there was no effect on the available nitrogen (N) concentration, which was attributable to a higher N immobilization rate. The increase in available P was similar in both soils in New South Wales with both bread wheat and canola residues. However, the increase in available S was higher with canola residue incorporation, which was associated with a lower C:S ratio (203.5 in the canola crop *v.* 1588.0 in the bread wheat crop) and higher S contribution with residue incorporation. Some authors have indicated that applying surface residue with minimum tillage in different crop rotations in Western Australia increased the organic C concentration in the first 30 cm soil depth and increased pH in the 20–30 cm stratum (Passaris *et al*., 2021). Another crop rotation study included corn, soybean (*Glycine max* (L.) Merr.), winter wheat/red clover (*Trifolium pratense* L.) crop combinations, surface or residue incorporation and N fertilization with ^{15}N and reported that residual N recovery in the grain of subsequent crops varied by crop type and rotation (Taveira *et al*., 2020). In that study, N recovery ranged from 9.7 to 13.5% for corn N residues in soybean seed, 26% for soybean N residues in corn grain and 30% for winter wheat/red clover N residues in corn grain (Taveira *et al*., 2020). In addition, it has been demonstrated that both crop rotation and residue incorporation affected soil C and N mineralization, which increased the C and N concentrations after residue incorporation with differences in magnitude depending on the crop rotation and fertilization rate being used (75 and 100% of the reference rate); there was a positive effect at the highest fertilization rate and when legumes were included in the rotation (Kumar *et al*., 2018).

There are limited reports on the effect of different residue incorporation levels in short-term rotations on the production of both canola and bean crops in volcanic soils under Mediterranean conditions. Therefore, our hypothesis is that the use of different crop rotations with incorporation of residues in different rates affects both grain yield and residue production on canola and bean crops. The objective of the present study was therefore to identify the best crop rotations for increasing grain yield and residue production in canola and bean crops after 5 years of a biannual crop rotation in a volcanic soil.

Materials and methods

The experiment was conducted over five consecutive seasons from 2016 to 2021 at the Santa Rosa Experimental Station, Instituto de Investigaciones Agropecuarias, INIA-Quilamapu, Chillán (36°31′ S; 71°54′ W), Chile. The soil is volcanic (Melanoxerand) and the climate is temperate Mediterranean characterized by a hot, dry summer and a cold, wet winter. Precipitation was 605, 563, 730, 460 and 576 mm for the 2016–2017, 2017–2018, 2018–2019, 2019–2020 and 2020–2021 seasons, respectively, which was concentrated in winter and spring. The mean temperature was 12.8, 13.2, 13.5, 13.4 and 14.3°C and evaporation was 1023, 1041, 990, 980 and 1060 mm for the five seasons, respectively.

Experiment management

The design of this experiment consisted of biannual rotations with six crop combinations: canola–bread wheat (*T. aestivum* L.), canola–durum wheat (*T. turgidum* L.), canola–corn (*Z. mays* L.), bean–bread wheat (*P. vulgaris* L.), bean–durum wheat and bean–corn in which residues of the previous crop were incorporated at levels of 0, 50, 100 and 200%. The basic design has been maintained since 2016, and the present article analyses the results for the canola and bean crops as the fifth crop in this biannual rotation (2020–2021 season).

At the beginning of the experiment, 3000 kg/ha lime was applied to correct soil acidity (Table 1) before sowing the canola and bean crops in April 2016; it was not necessary to apply lime over the next 3 years (Hirzel *et al*., 2021a, 2021c). There were three previous crops before the canola and bean crops in 2020–2021 season: (1) bread wheat ‘Pandora-INIA’ sown on 10 July 2019 and harvested on 22 January 2020, (2) durum wheat ‘Queule-INIA’ sown on 24 July 2019 and harvested on 30 January 2020 and (3) corn ‘DK-469’ (Dekalb) sown on 28 October 2019 and harvested on 24 April 2020.

The experimental unit for each crop (bread wheat, durum wheat and corn) previous to the canola or bean crops was a plot 40 m × 14 m (560 m^2) divided into four split plots for each residue level (140 m^2). Row spacing was 0.2, 0.2 and 0.7 m for the bread wheat, durum wheat and corn crops, respectively. The total experimental area was 13 440 m^2 and included six biannual crop rotations and four replicates, which were split when the experiment began in 2016. Each experimental unit was 560 m^2 with 24 experimental units, considering three previous crops (bread wheat, durum wheat and corn) × two second crops (canola and bean) × four replicates. Nitrogen, P (P_2O_5) and K (K_2O) fertilization rates were 240, 120 and 120 kg/ha in the bread wheat and durum wheat crops and 350, 120 and 120 kg/ha in the corn crop, respectively; these were based on soil chemical parameters (Table 1) and studies of N uptake in the three previous crops used in the present experiment. Both P and K were applied 100% at sowing in each of the three crops. Nitrogen was applied 15, 45 and 40% at the sowing, tillering and flag leaf stages, respectively, for the bread wheat and durum wheat crops, while N was applied 40% at sowing and 60% at the six-leaf stage for the corn crop. Fertilizer sources were urea, triple superphosphate and potassium chloride. Based on the soil chemical analysis (Table 1), Mg, S, Zn and B were applied at rates of 30:33:4:2 kg/ha before sowing in all crops with magnesium sulphate, zinc sulphate and calcium borate fertilizers. Once the three crops were harvested, residues were incorporated at levels of 0, 50, 100 and 200% (all residue from the 0% residue treatment was added to the 200% residue treatment) (May 2020) in the same experimental unit, and the plot was divided into four split plots 20 m× 7 m

Table 1. Soil chemical and physical parameters at the 0–0.2 m depth before initiating the crop rotation experiment (2016)

Parameters	Value
Clay (%)	16.7
Silt (%)	44.6
Sand (%)	38.7
Bulk density (g/cm^3)	1.00
pH $_{(soil:water\ 1:5)}$	5.52
Organic matter (g/kg)	109.2
Electrical conductivity (dS/m)	0.11
Available nitrogen (mg/kg)	54.1
Olsen phosphorus (mg/kg)	21.3
Exchangeable potassium ($cmol_c$/kg)	0.54
Exchangeable calcium ($cmol_c$/kg)	4.20
Exchangeable magnesium ($cmol_c$/kg)	0.36
Exchangeable sodium ($cmol_c$/kg)	0.08
Exchangeable aluminium ($cmol_c$/kg)	0.12
Available sulphur (mg/kg)	23.5

($140\ m^2$). Residue production was 8200, 8600 and 16 200 kg/ha for the bread wheat, durum wheat and corn crops, respectively. A displaceable mulcher (Tornado 310, Maschio Gaspardo, Campodarsego, Italy) was used to grind residues and a compact disk harrow (Rubin 9, Lemken GmbH and Co. KG, Alpen, Germany) to incorporate them.

The canola 'Imminent-SIS' was sown on 31 August 2020 and harvested on 25 January 2021. The inter-row spacing for this crop was 0.7 m. Irrigation was applied at the flowering stage. Total weed control was carried out with the propisochlor herbicide (Proponit 720 EC) at 1.44 a.i./ha, and disease control was not necessary. Nitrogen, P (P_2O_5) and K (K_2O) fertilization rates were 160, 120 and 80 kg/ha, respectively. Both P and K were applied 100% at sowing, while N was applied 50% at sowing and the remaining 50% at the 60% crop cover stage. Fertilizer sources were urea, triple superphosphate and potassium chloride. In addition, Mg, S, Zn and B were applied at rates of 30:33:4:2 kg/ha before sowing, which are the same as for the wheat and corn crops.

The bean crop 'Zorzal-INIA' was sown on 10 November 2020 and harvested on 11 March 2021. The inter-row spacing was 0.7 m. Irrigation was applied at the flowering stage. Total weed control was carried out with the fomesafen herbicide (Flex: 25%) at 0.25 a.i./ha at the first trifoliate leaf, and disease control was not necessary. The N, P (P_2O_5) and K (K_2O) fertilization rates were 60, 60 and 60 kg/ha, respectively. Nitrogen, P and K were applied 100% at sowing, and fertilizer sources were urea, triple superphosphate and potassium chloride. Same as for wheat and corn crops, also Mg, S, Zn and B were applied at rates of 30:33:4:2 kg/ha.

Canola and bean crop yield and residue production

The plots were manually harvested at grain maturity and threshed with a stationary thresher. Plant samples were collected from a $2.1\ m^2$ plot area and separated as grain and residue. Grain and tissue samples were oven-dried at 70°C for 72 h

Soil analysis before initiating the experiment in 2016

Composite samples were manually collected from the 0–20 cm soil depth for each treatment 2 months before sowing the canola crop. All samples were air-dried and sieved (2 mm mesh). Soil pH was determined in soil:water extracts (1:2.5 ratio). Soil organic C was established by Walkley–Black wet digestion (Sadzawka *et al.*, 2006). Soil inorganic N (NO_3-N and NH_4-N) was extracted with 2 M KCl and determined by colorimetry with a segmented flux spectrophotometer (autoanalyser, Skalar Analytical BV, Breda, The Netherlands). Soil extractable P was 0.5 M NaHCO3 (Olsen P) by the molybdate-ascorbic acid method. Exchangeable Ca, Mg, K and Na were determined by 1 M NH_4OAc extraction followed by atomic absorption (Ca and Mg) and flame emission (K and Na) spectroscopy. The soil exchangeable Al concentration was obtained with 1 M KCl extraction by atomic absorption spectroscopy. Sulphur (SO_4^{2-}) was determined with 0.01 M calcium phosphate and turbidimetry.

Experimental design and statistical analysis

For each second crop (bean and canola), a split-plot experimental design was used in which the main plot was the previous crop (three crops: bread wheat, durum wheat and corn) and the split plot was the residue level (four residue levels: 0, 50, 100 and 200%) with four replicates. Results were analysed by ANOVA and Tukey's test ($P = 0.05$) using the SAS PROC MIXED Model procedure (SAS Institute, Cary, North Carolina, USA). For the significant interactions between the previous crop and residue level, contrast analysis was used to compare individual treatment effects

Table 2. Canola and bean crop significance test for grain yield and residue production affected by three previous crops at four residue incorporation levels according to the split-plot design of the ANOVA test

Crop	Parameter	Previous crop (C)	Residue level (R)	C × R interaction
Canola	Yield	*	NS	NS
	Residue	*	*	NS
Bean	Yield	**	**	NS
	Residue	**	*	NS

*Significant at $P < 0.05$; **significant at $P < 0.01$; NS, not significant.

Results

The analysis of significance showed that canola grain yield was only significantly affected by the previous crop ($P < 0.05$), while canola residue production was affected by both the previous crop and residue incorporation level ($P < 0.05$) (Table 2). Bean grain yield was affected by both the previous crop and the residue incorporation level ($P < 0.01$). Residue production was also affected by both the previous crop ($P < 0.01$) and residue incorporation level ($P < 0.05$) (Table 2).

Canola grain yield and residue production

Canola grain yield varied between 2.34 and 3.81 Mg/ha; the highest yield was obtained after the corn crop, which only surpassed the yield obtained after the bread wheat crop ($P < 0.05$) (Table 3). Canola residue production fluctuated between 5.57 and 9.71 Mg/ha and was higher after the corn crop ($P < 0.05$) (Table 3). The effect of the residue level only occurred after the bread wheat crop ($P < 0.05$); the highest residue production was reached with 50% of the previous crop residue, which only surpassed the control without residue application ($P < 0.05$) (Table 3). Averaged over the three previous crops, the residue incorporation level had a directly proportional effect ($R = 0.88$, data not shown) on canola residue production (Table 2, Fig. 1).

Bean grain yield and residue production

Bean grain yield ranged from 3.55 to 5.24 Mg/ha, and the highest values were obtained after the corn crop; however, they were statistically similar to the values obtained after the durum wheat crop ($P < 0.05$) (Table 4). The effect of residue incorporation on bean grain yield only occurred after the bread wheat crop ($P < 0.05$), and there was a directly proportional effect between the two parameters (Table 4). Averaged over the three previous crops, the residue incorporation level had a directly proportional effect on bean grain production ($R = 0.96$, data not shown) (Table 2, Fig. 2). Averaged over the three previous crops, the residue incorporation level had no significant effect on bean residue production (data not shown).

Table 3. Canola crop grain yield and residue production affected by three previous crops at four residue incorporation levels

Previous crop	Residue level (%)	Grain yield (Mg/ha)	Residue production (Mg/ha)
Bread wheat	0	2.34Ba	6.25Bb
	50	3.29Ba	8.33Ba
	100	2.66Ba	7.02Bab
	200	3.40Ba	8.18Bab
Durum wheat	0	2.50ABa	5.57Ba
	50	2.90ABa	7.57Ba
	100	3.14ABa	7.86Ba
	200	3.31ABa	8.53Ba
Corn	0	3.81Aa	9.71Aa
	50	3.10Aa	8.87Aa
	100	3.37Aa	9.35Aa
	200	3.65Aa	9.41Aa

Different uppercase letters in the same column indicate significant differences between previous crops averaged over the four residue incorporation levels according to Tukey's test ($P < 0.05$).
Different lowercase letters in the same column for the same previous crop indicate significant differences between residue incorporation level treatments according to Tukey's test ($P < 0.05$). Mg = 1000 kg.

Discussion

The canola grain yield and residue production were normal for the study area, while they were higher for the bean crop for values reported in the same study area (Hirzel *et al.*, 2021a, 2021c). This was associated with the production potential of the genotype used in the fifth season of the experiment, which is one of the new genotypes that has been developed by the Legume Breeding Program of the Instituto de Investigaciones Agropecuarias (INIA). This genotype has also been used by farmers so far.

Positive effects of different crop rotations on crop grain yield and biomass production have also been described by some authors and could be associated with the effects on root exploration ability, nutrient recycling and weed control (Melander *et al.*, 2020; Passaris *et al.*, 2021; Sainju *et al.*, 2021; Sietz *et al.*, 2021). For the bean crop, the effect of the previous crop on grain yield has been reported with higher yields after the broccoli (*Brassica oleracea* L. var. *italica* Plenck) crop compared with faba bean (*Vicia faba* L.) green manure or fallow (Karavidas *et al.*, 2020; Meirelles *et al.*, 2021).

Crop rotation with residue incorporation affects the C and N mineralization processes and the regulation of the delivery of other nutrients from the residue itself and from soil reserves; this can positively affect crop nutrition and biomass and grain production (Kumar *et al.*, 2018; Xiao *et al.*, 2020). Therefore, the collection of soil samples in the future of this experiment and comparing the results of analysis with those from 2016 could provide more information about C and N dynamics under different crop rotations and residue incorporation levels; we hope to focus on this in our future efforts. This effect on canola grain and residue production and bean grain production was observed in our experiment with different crop rotations. Similarly, this effect was detected with increasing residue levels for canola residue production as an average of the three previous crops and bean grain production after the durum wheat crop. The highest grain and residue production was obtained after corn for the canola crop, which was associated with the higher incorporated residue mass in this crop and its effects on the supply of soil nutrients and C, as well as the higher N rate that was used (Kumar *et al.*, 2018). The highest bean grain yield was attained after the corn and durum wheat crops, although the incorporated residue mass with the durum wheat crop was lower than the corn crop. This can be explained by the different polyphenol composition and polyphenol:N ratio in the durum wheat crop, a higher lignin content in the corn crop and its effects on the soil microbial

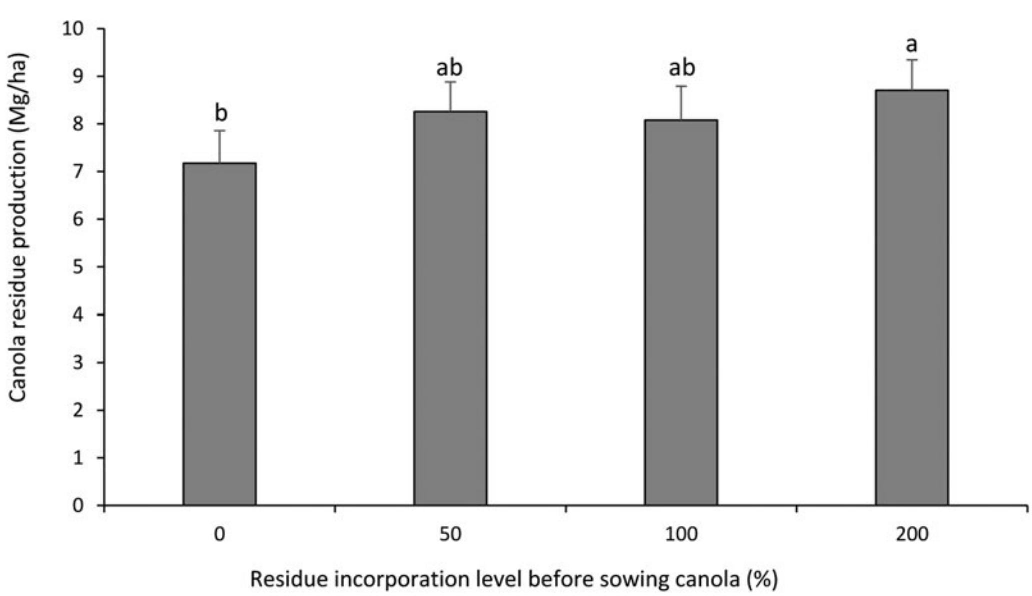

Fig. 1. Canola residue production affected by four residue incorporation levels (average of three previous crops) before sowing canola. Different letters over the bars indicate significant differences according to Tukey's test ($P < 0.05$). Lines over the bars correspond to the standard error. Mg = 1000 kg.

https://doi.org/10.1017/S0021859623000163 Published online by Cambridge University Press

Table 4. Bean crop grain yield and residue production affected by four residue incorporation levels of three previous crops

Previous crop	Residue level (%)	Grain yield (Mg/ha)	Residue production (Mg/ha)
Bread wheat	0	3.55Bb	4.65Ab
	50	3.66Bb	4.78Aab
	100	4.17Bab	5.97Aab
	200	4.55Ba	6.09Aa
Durum wheat	0	4.20Aa	6.12Aa
	50	4.31Aa	5.77Aa
	100	4.42Aa	5.74Aa
	200	4.71Aa	5.48Aa
Corn	0	4.39Aa	4.89Aa
	50	4.63Aa	5.58Aa
	100	4.59Aa	5.19Aa
	200	5.24Aa	7.26Aa

Different uppercase letters in the same column indicate significant differences between previous crops averaged over the four residue incorporation levels according to Tukey's test ($P < 0.05$).
Different lowercase letters in the same column for the same previous crop indicate significant differences between residue incorporation level treatments according to Tukey's test ($P < 0.05$). Mg = 1000 kg.

biomass activity and nutrient availability for the following crop (Chen *et al.*, 2017; Stagnari *et al.*, 2017; Kumar *et al.*, 2018; Manas and De Las Heras, 2018; Horvat *et al.*, 2020; Ingraffia *et al.*, 2020). The observed response to an increased residue level can also be explained by the higher incorporated residue mass and its effects on the supply of nutrients and C to the soil (Kumar *et al.*, 2018).

Given that N was not applied along with residue incorporation in our experiment, we could have expected a negative effect on N availability associated with the immobilization process, which is known as N starvation (Sarker *et al.*, 2019). However, a suitable condition was generated for nutrient mineralization in the residues in soils with a high organic matter content in which shredded crop residues were incorporated 4–7 months before planting the following crop together with winter rains. An experiment showed that applying treatments with C, N and P in different andosols with a different management history in Mount Kilimanjaro produced a priming effect on soil C mineralization, which suggested that increased N availability accelerated the mineralization of native soil organic matter (Mganga and Kuzyakov, 2018). The organic composition of C compounds in the incorporated residues in our experiment was comparatively simpler than passive and active soil organic matter (Kogel-Knabner, 2002; Lehmann *et al.*, 2007). Residual fertilization of the crop system and soil N mineralization can contribute to the N needs of the soil biomass to achieve residue decomposition (Mganga and Kuzyakov, 2018; Piazza *et al.*, 2020). Exudation of C compounds is generated from the roots during a new crop cycle, which activates soil biomass, contributes to the mineralization of soil organic matter and can also assist in residue decomposition of the previous crop (Kuzyakov, 2002; Xiao *et al.*, 2015; Piazza *et al.*, 2020).

For the conditions of our experiment, the results indicated that canola grain yield was affected by the previous crop, while canola residue production was affected by both the previous crop and residue level with a directly proportional effect of the applied residue level. Bean grain yield was affected by both the previous crop and residue level, while bean residue production was only affected by the residue level. The residue level had a directly proportional effect on grain yield and residue production only after the durum wheat crop. Both canola grain yield and residue production were higher after the corn crop, while bean grain yield was higher after the durum wheat and corn crops. Our results suggest that the effect of residue management on crop productivity in the future

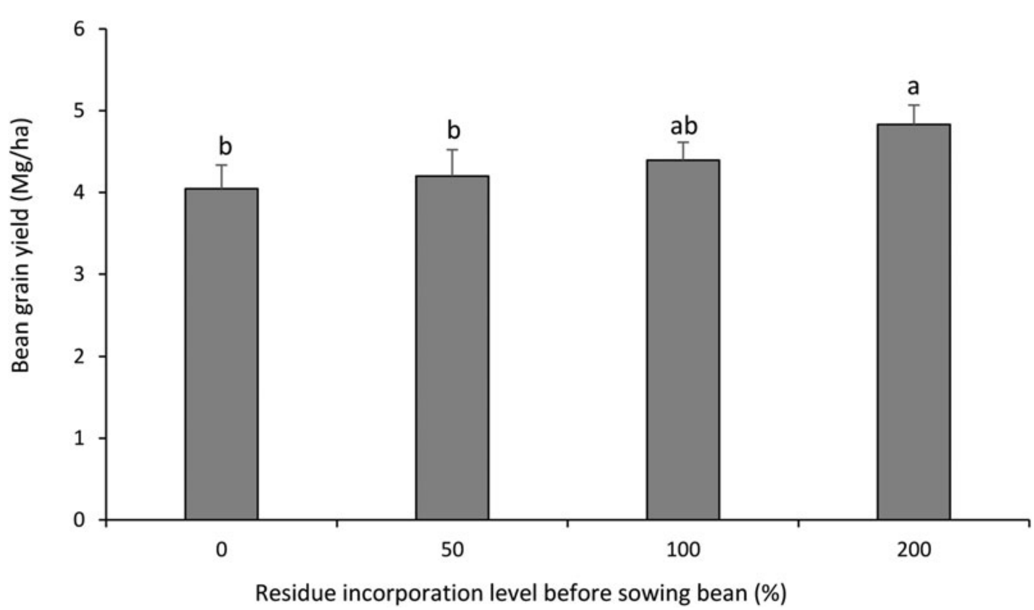

Fig. 2. Bean grain yield affected by four incorporation residue levels (average of three previous crops) before sowing bean. Different letters over the bars indicate significant differences according to Tukey's test ($P < 0.05$). Lines over the bars correspond to the standard error. Mg = 1000 kg.

https://doi.org/10.1017/S0021859623000163 Published online by Cambridge University Press

could be associated with climatic conditions and microbiological, physical and chemical soil parameters.

Conclusion

Overall, the best crop rotation for canola grain yield was corn–canola, which produced 0.54 Mg/ha (18.3%) higher yield than the average of the other two rotations. The best crop rotation for achieving higher bean grain yield was corn–bean, which yielded 0.52 Mg/ha (12.3%) higher than the average of the other two rotations. Finally, residue incorporation at different levels had a slightly positive effect on canola and bean residue production following the bread wheat crop. It would be interesting to assess the different responses of the evaluated parameters for corn as the previous crop and for bread wheat as the previous crop associated with residue incorporation.

Author contributions. Conceptualization: J. H. and P. U.; methodology: J. H., P. U. and I. M.; formal analysis: J. H. and L. L.; investigation: J. H., L. L. and I. M.; writing – review and editing: J. H. and P. U.; all authors have read and agreed to the published version of the manuscript.

Financial support. This research was funded by the Chilean Agricultural Research Institute (INIA).

Conflict of interest. None.

Ethical standards. Not applicable.

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