Medical Research Archives

ESMED
European Society of Medicine

OPEN ACCESS

Published: June 30, 2023

Citation: Hirzel J, Undurraga P, et al., 2023. Different Crop Rotations and Residue Levels as They Affect Corn Grain, Residue Production, and Nutrient Concentration, Medical Research Archives, [online] 11(6). https://doi.org/10.18103/mra.v11i6.3923

DOI
https://doi.org/10.18103/mra.v11i6.3923

ISSN: 2375-1924

RESEARCH ARTICLE

Different Crop Rotations and Residue Levels as They Affect Corn Grain, Residue Production, and Nutrient Concentration

Juan Hirzel[1]*, Pablo Undurraga[1], Iván Matus[1], and Pascal Michelow[2].

[1]Instituto de Investigaciones Agropecuarias, CRI Quilamapu, Avenida Vicente Méndez 515, Chile.
[2]Semillas Generación 2000, Carlos Sanhueza 35, Vilcún, Chile.

***Corresponding author:** jhirzel@inia.cl.
ORCID 0000-0002-2710-987X

ABSTRACT

The consumption of corn-based foods is a good alternative for human health due to their high content of proteins, essential amino acids and polyunsaturated fatty acids of the omega-3 family. The present study evaluated the effect of two medium-term canola (*Brassica napus* L.)-corn (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.)-corn rotations with four residue incorporation rates (0%, 50%, 100% and 200% of the preceding crop) on corn grain yield, residue production, nutrient concentration and extraction after two rotation cycles in a volcanic soil of south-central Chile. Results indicated that grain yield ranged from 17.04 to 17.40 Mg ha^{-1}, and residue production ranged from 16.41 to 16.50 Mg ha^{-1}, being unaffected by the preceding crop. Residue incorporation rates had no effect on grain yield and residue production. The preceding crop affected the concentration and extraction of some nutrients in grain and residue. Residue rate affected the concentration and extraction of some nutrients in grain only. Ca distribution in corn grain was negatively affected by the preceding bean crop and increased residue incorporation rate. Nutrient concentration in grain ranged from 1.33 to 1.36% for N, 0.33% for P, 0.53 to 0.54% for K, 0.008 to 0.011% for Ca, 0.14% for Mg, and 0.087 to 0.092% for S. The ranking of total macronutrient extraction in the corn crop was K > N > Ca > P > Mg > S. The extraction means ranged from 320.0 to 325.8, 56.0 to 57.1, 364.7 to 373.7, 86.5 to 99.3, 39.4 to 42.4, and 22.6 to 23. 7 kg ha^{-1}, while grain nutrient partitioning coefficients ranged from 64.5 to 66.8, 90.1 to 90.9, 23.1 to 23.7, 1.3 to 2.0, 50.8 to 57.5, and 60.3 to 60.6 for N, P, K, Ca, Mg, and S, respectively. The use of bean as a previous crop allowed an increase in grain protein content (8.56 vs. 8.30%) with respect to the canola crop.

Introduction

Corn is a crop of high nutritional value with great importance for human health [1]. The estimated area under corn (*Zea mays* L.) cultivation in 2020 was 192 million ha. worldwide [2]. In Chile, this area was between 90,000 and 110,000 ha and gross primary productivity was 12 to 14 Mg C ha^{-1} yr^{-1} [3], lower than the results indicated for the US Midwest by Wingeyer [4]. Given the high nutritional demand of this crop [5,6], conservation practices to recycle preceding crop residues and include crop rotations would contribute in reducing fertilization of this crop, thus improving its productive potential [7-9]. Conservation practices improve soil physical properties, decrease the risk of soil erosion and increase its productive potential [7,10-12]. In addition, conservation practices positively affect soil nutrient cycling, mainly nitrogen (N) and carbon (C) and increase N use efficiency [10,13-15]. Soil biological activity also improves with conservation practices [12,16-18]. Crop rotation increases grain yield in cereals such as corn and bread wheat (*Triticum aestivum* L.) compared to monoculture of both species [19]. Pandiaraj [15] showed that grain yield of wheat was higher after green grama (*Vigna radiate* [L.] Wilczek) compared to corn as a preceding crop because mineral N in the root zone of the soil is usually higher in a cereal-legume cropping system than in cereal monoculture. For durum wheat (*T. turgidum* L.), Hirzel [20] indicated that grain yield increased when the preceding crop was white lupin or narrow-leafed lupin compared to durum wheat monoculture. Similarly, several authors [10,15,21] have shown that residue incorporation increases grain yields, such as in bread wheat. In contrast to the benefits of residue incorporation indicated by different authors, Limón-Ortega [13] observed a 0.2 Mg ha^{-1} decrease in grain yield in bread wheat monoculture when residue was incorporated instead of burned. Swanepoel [22] conducted an experiment for two consecutive seasons with a canola crop and three bread wheat residue rates (high, intermediate and low of 5.1 to 6.4, 4.3 to 5.3 and 1.5 to 1.9 Mg ha^{-1}, respectively) and two tillage systems (tine openers and disc openers). They indicated that the residue level of the preceding crop affected the initial plant population and biomass production up to 60 d after sowing without affecting the canola crop yield; they concluded that canola can tolerate some residue rates.

It is important to quantify the benefits of residue incorporation from previous crops, and to consider that adverse factors to this practice are the possible phenomenon known as "N starvation" and the difficulty of establishing a crop in the presence of residues, which could occur in some soils. Agricultural production systems with residue incorporation usually produce long-term effects, but there is little information on medium-term experiments. We hypothesize that different rates of residue incorporation of these two preceding crops may positively affect corn grain yield, plant nutrient concentration and extraction, and grain protein content, and justify the application of residue incorporation as a soil conservation method or cultural technique. In addition, there is insufficient information on the maximum residue rate that does not adversely affect subsequent crop yield or on the possible interaction between plant species and residue rate. The objective of the present study was to determine the effect of two medium-term biannual rotations and four rates of incorporated and/or imported residues on corn grain yield, residue production, nutrient concentration and extraction, and grain protein content.

Methods

The experiment was conducted from 2016 to 2020 at the Santa Rosa Experimental Station, INIA-Quilamapu, Chillán, Chile (36°31' S, 71°54' W). The soil is of volcanic origin (Melanoxerand) and has a low effective depth (0.45 m) [23]. The climate is temperate Mediterranean with a hot, dry summer and a cold, wet winter. Precipitation was 605, 563, 730, and 460 mm for the 2016-2017, 2017-2018, 2018-2019, and 2019-2020 seasons, respectively, which were concentrated in winter and spring. Mean temperature was 12.8, 13.2, 13.5, and 13.4 °C and evaporation was 1,023, 1,041, 990, and 980 mm for the 2016-2017, 2017-2018, 2018-2019, and 2019-2020 seasons, respectively.

Since the objective was to evaluate the effect of two preceding crops and four residue rates for each crop on both productive and nutritional parameters, the results were evaluated and analyzed for the corn crop after two crop rotation cycles (2019-2020 season).

Experiment management

The crop rotations were canola (*Brassica napus* L.)-corn (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.)-corn; agronomic practices normally used in Chile for these crops were standardized for the Chillán location. Cultivars were Eminem-von Baer and Imminent-SIS for canola (first and third seasons, respectively), Torcaza-INIA for bean (first and third seasons), and DK-469 and DK-585 (Dekalb) for corn (second and fourth seasons, respectively).

The sowing dates for the first season of the experiment were May 15 and October 27, 2016 and harvest dates were April 5 and February 28, 2017 for canola and bean, respectively. In the second season, corn was sown on October 25, 2017 and harvested on April 22, 2018. In the third season, canola was sown on May 25, 2018 and harvested on January 15, 2019, while bean were sown on October 27, 2018 and harvested on February 28, 2019. In the fourth season, corn was planted on October 27, 2019 and harvested on April 15, 2020.

Each experimental unit was 40 m long and 14 m wide (560 m^2 plot) with row spacing of 0.7, 0.7, and 0.7 m for canola, beans, and corn, respectively. Seed rates were 30, 120, and 40 kg ha^{-1} for canola, bean, and corn, respectively. Irrigation was applied to the canola crop at the flowering stage and at the beginning of the grain filling stage. Irrigation for bean was applied at 80% crop coverage, 75% at flowering, and at the beginning of the grain filling stage. Irrigation in corn was applied weekly from the beginning of November 2017 to March 15, 2018 (second season) and from the beginning of November 2019 to March 20, 2020 (fourth season). Total weed control was carried out and disease control was not necessary. Lime was applied at the rate of 3,000 kg ha^{-1} prior to sowing canola and bean in April 2016. Fertilization rates of nitrogen (N), phosphorus (P) as P_2O_5, and potassium (K) as K_2O were 160, 120, and 80 kg ha^{-1} for the canola crop, 60, 60, and 60 kg ha^{-1} for the bean crop, and 350, 120, and 120 kg ha^{-1} for the corn crop, respectively, in accordance with soil chemical properties (Table 1). In the three crops, P and K were applied 100% at sowing, while N was applied 50% at sowing and 50% at 80% crop coverage in canola, 100% at sowing in bean, and 40% at sowing and 60% at the 6-leaf stage in corn. Fertilizers used were urea, triple superphosphate, and potassium chloride. In addition, magnesium (Mg), sulfur (S), zinc (Zn), and boron (B) were applied as magnesium sulphate, zinc sulphate, and calcium borate fertilizers in all the crops at rates of 30:33:8:4:2 kg ha^{-1} before sowing according to soil analysis (Table 1). In the first season, average grain yields of canola and bean were 3.2 and 3.8 Mg ha^{-1}, respectively, and residue production was 8.0 and 7.3 Mg ha^{-1} for canola and bean, respectively. For the second season, corn grain yields ranged between 15.7 and 17.5 Mg ha^{-1} and residue production between 16.0 and 16.8 Mg ha^{-1} with no significant differences associated with the preceding crop [6]. For the third season, average grain yields were 4.3 and 3.7 Mg ha^{-1} and residue production was 10.3 and 7.2 Mg ha^{-1} for canola and bean, respectively. At harvest, canola and bean residues were ground and incorporated at rates of 0%, 50%, 100%, and 200% in the same experimental unit; the plot was divided into four split-plots 20 m long and 7 m wide (140 m^2). The equipment used to grind and incorporate the residues were Maschio, (Model Tornado 310, Gaspardo S.p.A.) and Lemken (Model Rubin 9, Lemken GmbH & Co. KG), respectively.

Corn grain yield, residue yield, and plant tissue analysis

Plots were harvested manually at grain maturity, and both grain yield and residue production for each plot were expressed in Mg ha^{-1}. Plant samples from a 2.1 m^2 plot area were collected and separated into grain and aerial residue. Grain and residue samples were oven-dried at 70 °C for 72 h.

The concentrations of N, P, K, calcium (Ca), Mg and S in the grain and in the aerial residue were determined. The dry subsamples were ground with a mill, passed through a 2-mm sieve, and analyzed. After dry-ashing at 500 °C and acid digestion (2M HCl), total N was determined by the macro-Kjeldahl procedure and total K, Ca, and Mg by atomic emission (K) and atomic absorption (Ca and Mg) spectrophotometry. Phosphorus was measured in the same extracts by colorimetry according to the molybdate ascorbic acid method. The turbidimetric method was used to determine sulfate as barium chloride [24]. Grain protein content was estimated with the conversion coefficient of N-form to protein content, which corresponded to 6.25.

Nutrient extraction in grain or residue was determined by the ratio of grain yield to nutrient concentration or residue yield to nutrient concentration. The distribution coefficient of nutrients in grain was determined as the percentage ratio between the extraction in grain and the total extraction of each nutrient.

Experimental design and statistical analysis

The experimental design was a split-split plot in which the main plot was the crop rotation (2) and the split plot was the residue rate (4) with four replicates.

Results were analyzed by ANOVA and Tukey's test ($p = 0.05$) using the SAS PROC MIXED Model procedure [25]. Contrast analysis for significant interactions was used to compare treatment effects individually.

Results

Significance analysis

Significance analysis indicated no effect of preceding crop or residue rate on grain yield and residue production ($p < 0.05$) (Table 2). The preceding crop only affected N, protein, Ca, and S concentrations in the grain and Ca and Mg concentrations in the residue ($p < 0.01$). Meanwhile, the preceding crop affected Ca ($p < 0.01$) and S ($p < 0.05$) extraction in the grain and Ca and Mg in the residue ($p < 0.01$). The distribution coefficient of Ca and Mg to grain was also affected by the preceding crop ($p < 0.01$) (Table 2). Residue incorporation rate only affected N, Ca, and Mg concentrations in the grain, but interacted with the preceding crop ($p < 0.05$). The interaction with preceding crop and residue incorporation rate affected grain P ($p < 0.01$) and residue Mg ($p < 0.05$) concentrations. The N, P, and Ca extraction in grain was also affected by residue rate, but with the interaction of the preceding crop ($p < 0.05$). Meanwhile, Mg extraction in grain was affected by preceding crop and residue rate ($p < 0.05$). Residue rate also affected the distribution coefficient of Ca in grain, with the interaction of the preceding crop ($p < 0.05$) (Table 2).

Table 1. Soil chemical properties at the 0-0.2 m depth before sowing canola and bean crops at the start of the four-year rotation (2016-2017 season).

Parameters	Value
Clay, %	16.70
Silt, %	44.60
Sand, %	38.70
Bulk density, g cm^{-3}	1.00
pH (soil:water 1:5)	5.52
Organic matter, g kg^{-1}	109.20
EC, dS m^{-1}	0.11
Available N, mg kg^{-1}	54.10
Olsen P, mg kg^{-1}	21.30
Exchangeable K, cmol_c kg^{-1}	0.54
Exchangeable Ca, cmol_c kg^{-1}	4.20
Exchangeable Mg, cmol_c kg^{-1}	0.36
Exchangeable Na, cmol_c kg^{-1}	0.08
Exchangeable Al, cmol_c kg^{-1}	0.12
Available Fe, mg kg^{-1}	28.30
Available Mn, mg kg^{-1}	1.70
Available Zn, mg kg^{-1}	0.20
Available Cu, mg kg^{-1}	1.20
Available B, mg kg^{-1}	0.10
Available S, mg kg^{-1}	23.50

EC: Electrical conductivity.

Table 2. Significance analysis of corn yield and nutrient concentrations in grain and residue for the second corn crops in a four-year rotation.

Parameter		Previous crop (C)	Residue rate (R)	C * R Interaction
Grain production		NS	NS	NS
Residue production		NS	NS	NS
Grain nutrients concentration	N	**	**	**
	P	NS	NS	**
	K	NS	NS	NS
	Ca	**	**	**
	Mg	NS	*	*
	S	**	NS	NS
Grain nutrients extraction	N	NS	*	*
	P	NS	*	*
	K	NS	NS	NS
	Ca	**	**	**
	Mg	NS	NS	*
	S	*	NS	NS
Residue nutrients concentration	N	NS	NS	NS
	P	NS	NS	NS
	K	NS	NS	NS
	Ca	**	NS	NS
	Mg	**	NS	*
	S	NS	NS	NS
Residue nutrients extraction	N	NS	NS	NS
	P	NS	NS	NS

	K	NS	NS	NS
	Ca	**	NS	NS
	Mg	**	NS	NS
	S	NS	NS	NS
Grain nutrients distribution coefficient	N	NS	NS	NS
	P	NS	NS	NS
	K	NS	NS	NS
	Ca	**	*	*
	Mg	**	NS	NS
	S	NS	NS	NS

* Significant at the 0.05 probability level; **Significant at the 0.01 probability level; NS: nonsignificant.

Corn grain yield and residue production

Grain yield and residue production ranged from 17.04 and 17.40 and 16.41 and 16.50 Mg ha^{-1}, respectively, (Table 3), with no effect of preceding crop or residue incorporation rate. Given these values for grain yield and residue production, which were averaged for all residue doses used in each rotation, the coefficient of dry matter distribution to corn grain can be calculated as the average for each rotation; thus, values of 49.0 and 48.6 were obtained when corn was grown after oilseed rape and beans, respectively.

Table 3. Corn yield and nutrient concentrations in grain and residue after the canola or bean crops for the second corn crop in a four-year rotation.

Tissue	Parameter	2019-20 season Preceding crop	
		Canola	Bean
Grain	Yield, Mg ha^{-1}	15.80 a	15.58 a
	N concentration, %	1.328 b	1.369 a
	Protein content, %	8.30 b	8.56 a
	P concentration, %	0.326 a	0.327 a
	K concentration, %	0.533 a	0.539 a
	Ca concentration, %	0.011 a	0.008 b
	Mg concentration, %	0.143 a	0.138 a
	S concentration, %	0.087 b	0.092 a
Residue	Residue, Mg ha^{-1}	16.41 a	16.50 a
	N concentration, %	0.711 a	0.645 a
	P concentration, %	0.035 a	0.031 a
	K concentration, %	1.760 a	1.695 a
	Ca concentration, %	0.518 b	0.595 a
	Mg concentration, %	0.102 b	0.127 a
	S concentration, %	0.054 a	0.057 a

Different letters in the same row indicate differences according to Tukey's test ($p < 0.05$).

Nutrient concentrations and protein content in the corn grain

Most of the nutrient concentrations in the grain were affected by the interaction between the preceding crop and the residue incorporation rate (Tables 2 and 3). The N concentration and protein content were higher after the bean crop ($p < 0.05$); however, both N concentration and protein content in the grain significantly increased with the three highest residue incorporation rates after the canola crop (Figure 1). The P concentration was also affected by the canola residue rate but its effect was erratic because the highest value was obtained with 100% residue (Figure 2). The Ca concentration was higher after the canola cultivation ($p < 0.05$). After bean cultivation, there was an inversely proportional relationship between the residue incorporation rate and Ca concentration obtained in corn grain (Figure 3); there were no significant differences between the three highest residue rates ($p > 0.05$). The Mg concentration after canola cultivation showed an erratic effect with respect to residue incorporation rates and was highest at the 100% (Figure 4). The S concentration was higher after the bean crop ($p < 0.05$).

The ranking of nutrient concentrations in the corn grain was N > K > P > Mg > S > Ca (Table 3).

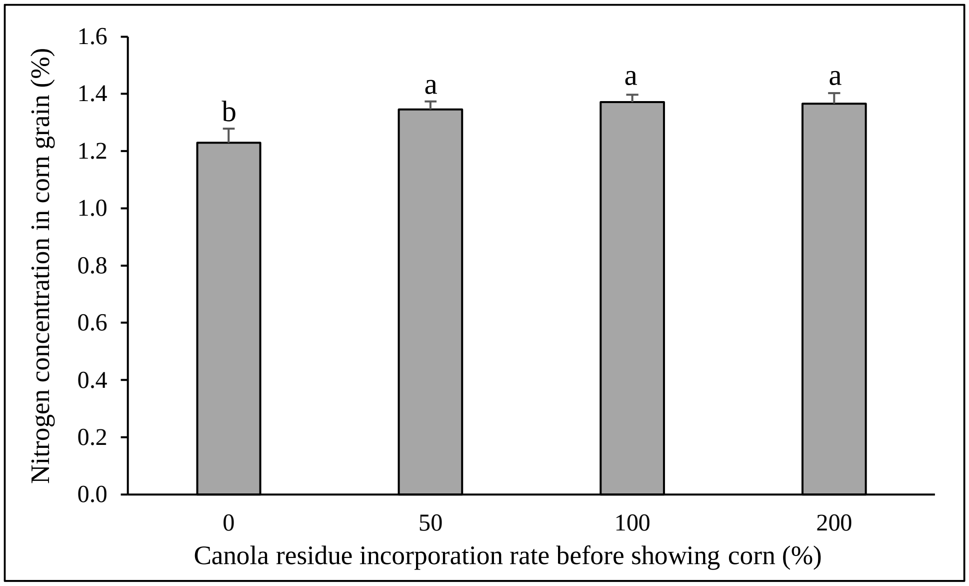

Figure 1. Nitrogen concentration in corn grain for the second rotation season (2019-2020) after four residue incorporation rates of canola crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

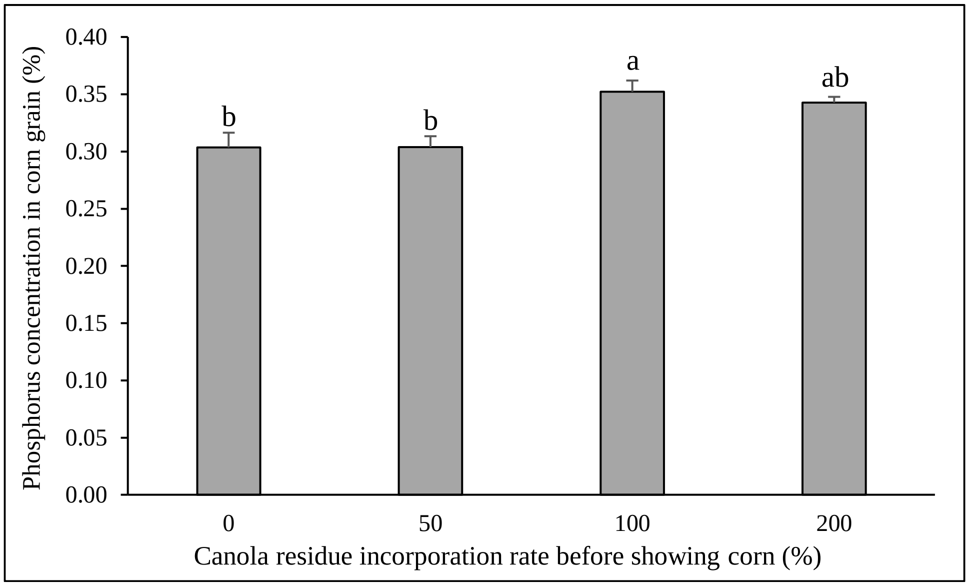

Figure 2. Phosphorus concentration in corn grain for the second rotation season (2019-2020) after four residue incorporation rates of canola crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

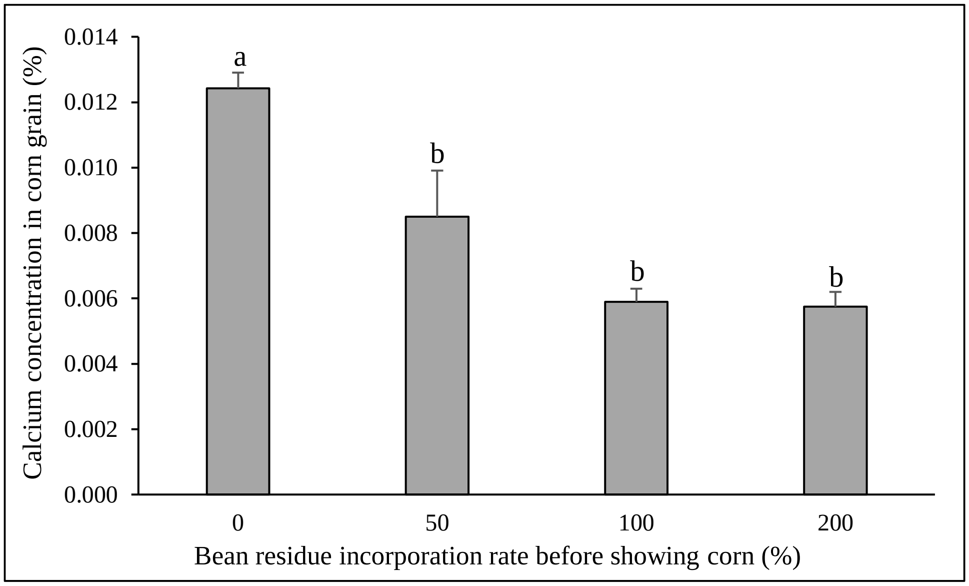

Figure 3. Calcium concentration in corn grain for the second rotation season (2019-2020) after four residue incorporation rates of bean crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

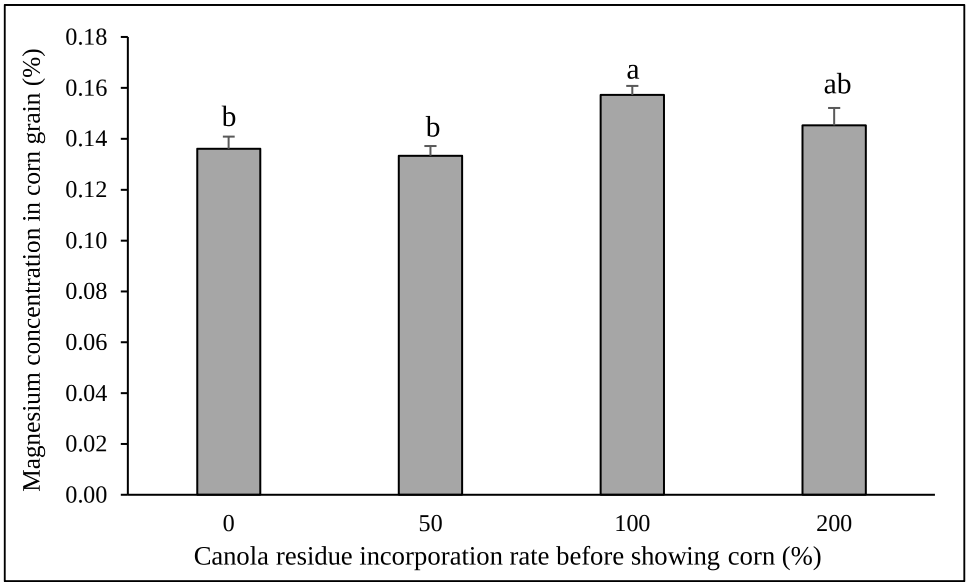

Figure 4. Magnesium concentration in corn grain for the second rotation season (2019-2020) after four residue incorporation rates of canola crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

Nutrient concentrations in the corn residue

Most nutrient concentrations were not affected by the preceding crop or residue incorporation rate (Tables 2 and 3). The Ca and Mg concentrations were higher after the bean crop ($p < 0.05$); Mg concentration was inversely proportional to the rate of bean residue incorporation before sowing the corn crop (Figure 5), and the lowest value was obtained with the highest residue rate ($p < 0.05$). The ranking of the nutrient concentrations in the corn residue was K > N > Ca > Mg > S > Ca (Table 3).

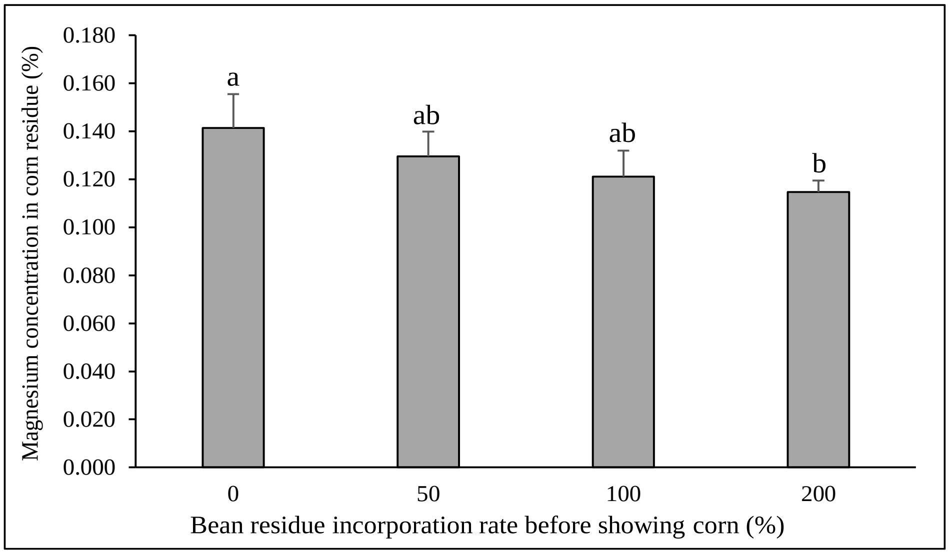

Figure 5. Magnesium concentration in corn residue for the second rotation season (2019-2020) after four residue incorporation rates of bean crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

Nutrient extractions in corn grain

Most nutrient extractions in corn grain were affected by the interaction between the preceding crop and the residue incorporation rate, except for K and S; however, S extraction was affected by preceding crop (Tables 2 and 4). N extraction was directly proportional to the rate of canola residue incorporation (Figure 6), and the highest values were obtained at the two highest residue rates ($p < 0.05$). P extraction was higher in the two highest rates of canola residue ($p < 0.05$) (Figure 7). Ca extraction was higher after canola cultivation ($p < 0.05$) (Table 4). After bean cultivation, there was an inversely proportional relationship between Ca concentration and residue incorporation rate (Figure 8); the lowest extractions were obtained at the two highest residue rates, exceeded only by the control without residue incorporation ($p < 0.05$). Mg extraction was erratic for the different rates of canola residue incorporation (Figure 9), with the highest value obtained at 100% residue ($p < 0.05$). S extraction was higher after bean crop ($p < 0.05$) (Table 4). The ranking of nutrient extractions in corn grain was N > K > P > Mg > S > Ca (Table 4).

Table 4. Nutrient extraction in grain and residue and nutrients distribution coefficient after the canola or bean crops for the second corn crop in a four-year rotation.

Tissue	Parameter	2019-20 season Preceding crop	
		Canola	Bean
Grain	N extraction, kg ha^{-1}	209.3 a	213.2 a
	P extraction, kg ha^{-1}	51.4 a	50.9 a
	K extraction, kg ha^{-1}	83.8 a	83.7 a
	Ca extraction, kg ha^{-1}	1.7 a	1.3 b
	Mg extraction, kg ha^{-1}	22.7 a	21.6 a
	S extraction, kg ha^{-1}	13.7 b	14.3 a
Residue	N extraction, kg ha^{-1}	116.5 a	106.8 a
	P extraction, kg ha^{-1}	5.7 a	5.1 a
	K extraction, kg ha^{-1}	289.5 a	281.0 a
	Ca extraction, kg ha^{-1}	84.8 b	98.1 a
	Mg extraction, kg ha^{-1}	16.8 b	20.8 a
	S extraction, kg ha^{-1}	8.9 a	9.4 a
Grain nutrients distribution coefficient (%)	N	64.5 a	66.8 a
	P	90.1 a	90.9 a
	K	23.1 a	23.7 a
	Ca	2.0 a	1.3 b
	Mg	57.5 a	50.8 b
	S	60.6 a	60.3 a

Different letters in the same row indicate differences according to Tukey's test ($p < 0.05$).

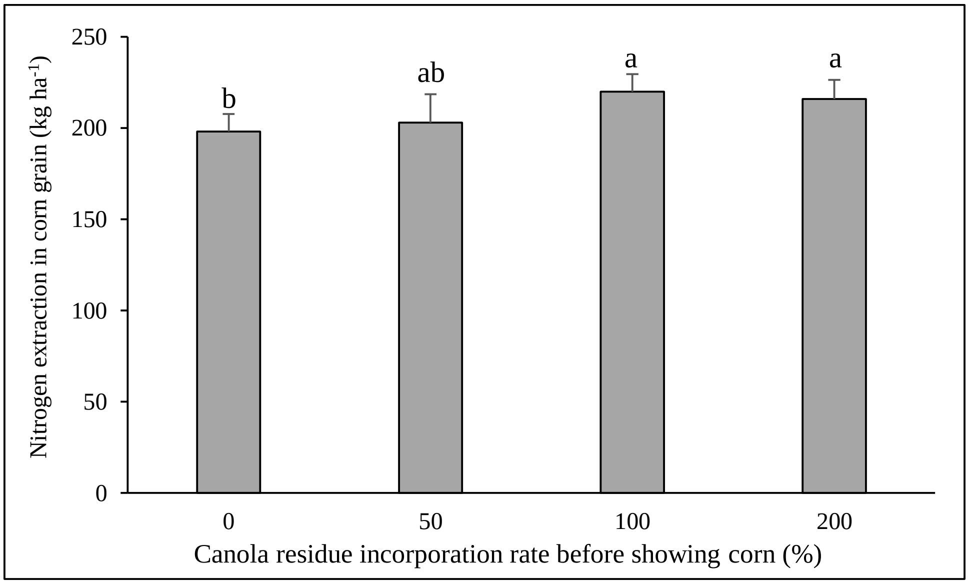

Figure 6. Nitrogen extraction in corn grain for the second rotation season (2019-2020) after four residue incorporation rates of canola crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

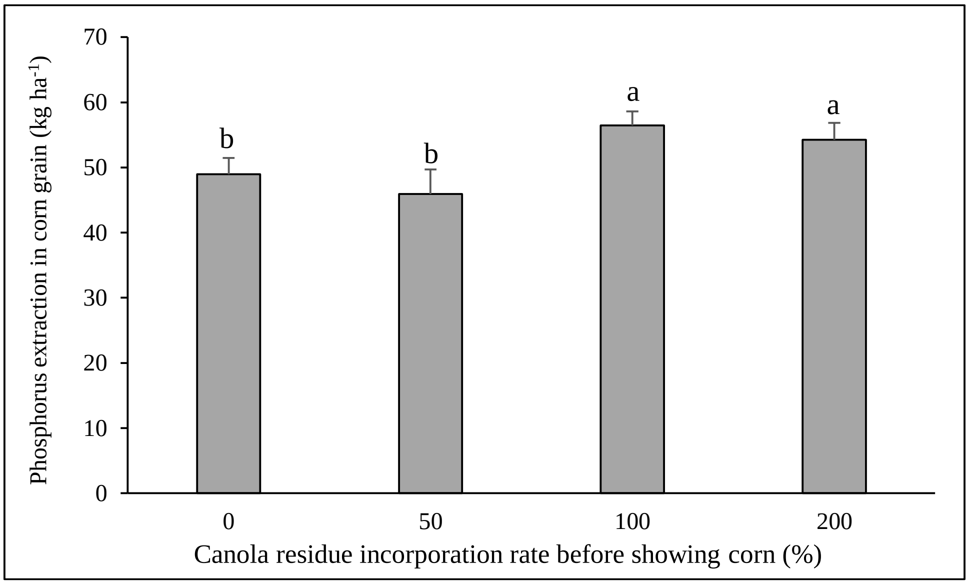

Figure 7. Phosphorus extraction in corn grain for the second rotation season (2019-2020) after four residue incorporation rates of canola crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

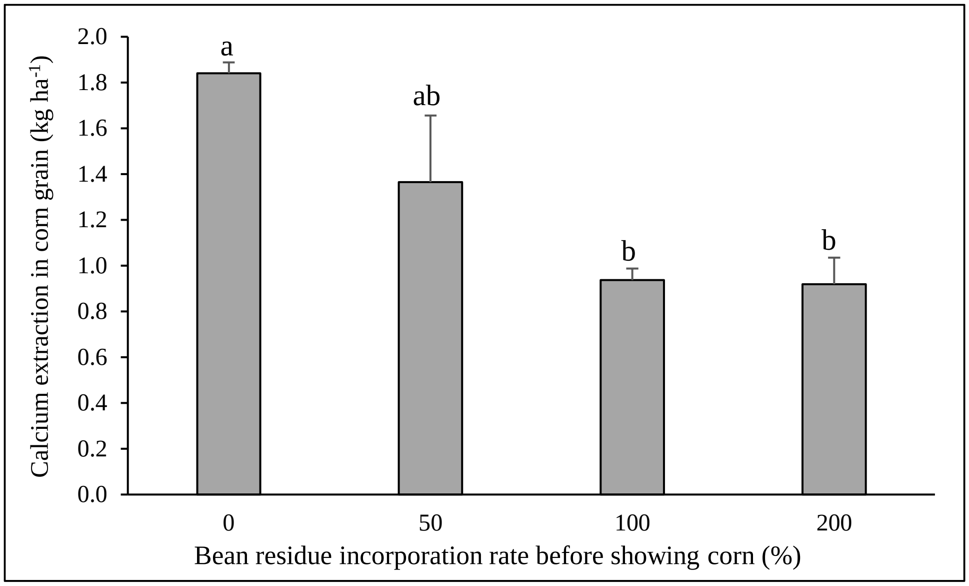

Figure 8. Calcium extraction in corn grain for the second rotation season (2019-2020) after four residue incorporation rates of bean crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

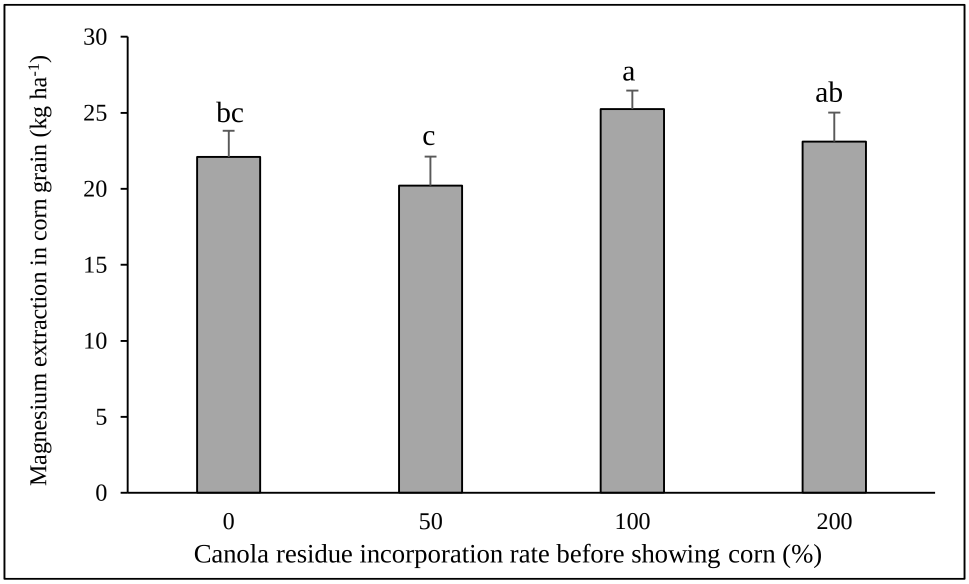

Figure 9. Magnesium extraction in corn grain for the second rotation season (2019-2020) after four residue incorporation rates of canola crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

Nutrient extractions in corn residue

Most nutrient extractions in the corn residue were not affected by the preceding crop (except Ca and Mg), residue incorporation rate, or by the interaction of both factors (Tables 2 and 4). Ca and Mg extractions in the residue were higher after bean cultivation ($p < 0.05$) (Table 4).

The ranking of nutrient extractions in corn residue was K > N > Ca > Mg > S > P (Table 4).

Distribution coefficient of nutrients to the grain

The partition coefficient for most nutrients to corn grain was not affected by the preceding crop, residue rate or the interaction between the two factors (Tables 2 and 4). The value for Ca was higher after the canola crop ($p < 0.05$) (Table 4); however, it was inversely proportional to the residue incorporation rate after the bean crop (Figure 10), and the lowest distribution coefficient values to grain were obtained at the two highest residue incorporation rates ($p < 0.05$).

The ranking of the nutrient distribution coefficients in the grain was P > N > S > Mg > K > Ca (Table 4).

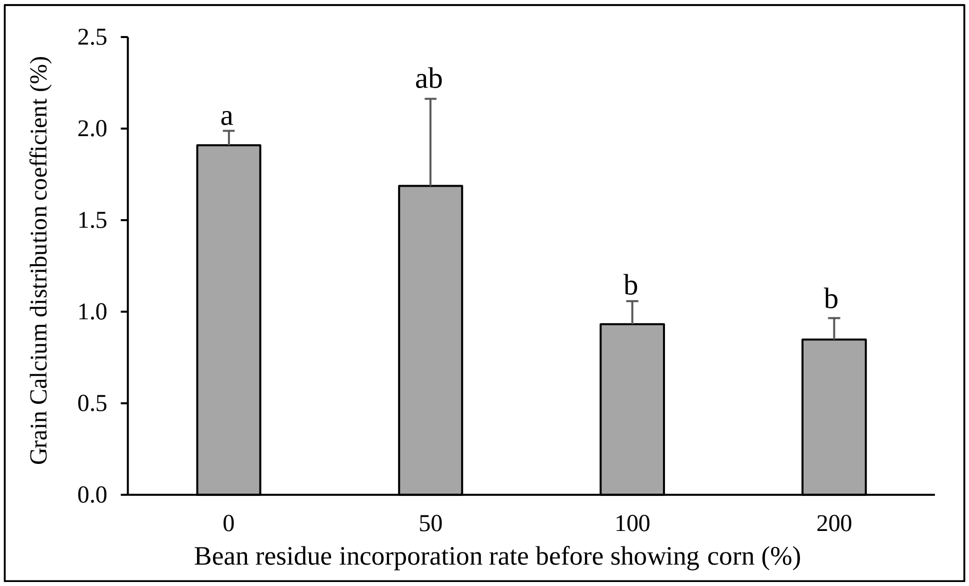

Figure 10. Grain Calcium distribution coefficient for the second rotation season (2019-2020) after four residue incorporation rates of bean crops. Different letters over the bars indicate differences according to Tukey's test ($p < 0.05$). Lines over the bars correspond to the standard error.

Discussion

Corn grain yield and residue production were normal for the study area [6,7,26]; other authors have mentioned the lack of effect of preceding crop or residue rate on yield in short- and medium-term studies [6,7,22,27]. The lack of effect of residue rate on grain yield and residue production can be explained by the high organic matter (OM) level at the experimental site, which may reduce the response to organic C addition derived from residue incorporation during the experiment. Corn grain yield and residue production in the present experiment were higher than the results reported by Woli [28] in field experiments conducted in Iowa, USA, and by Overmann and Scholtz [29] for a production model based on Northern Hemisphere data, which is likely associated with the lower productive potential of these soils compared to the soil used in our experiment. In addition, the coefficients of dry matter distribution to corn grain are normal for the study area [30].

Increased concentration of some nutrients and grain protein content in corn plant tissues following a legume crop like bean has been reported by other authors, mainly for N [9,13, 31-33], associated with increased soil biomass activity [8,12,17,34] and its effect on nutrient supply.

The higher residue incorporation rate of both preceding crops may have produced a higher nutrient availability for the corn crop, resulting in a higher concentration of nutrients in both grains and residue. This was partially observed in some nutrients, probably associated with the adequate soil fertility (Table 1) and fertilization used in this experiment, which meets the crop needs for this production condition [6,26]. The higher Ca concentration obtained in corn grain after canola cultivation may be due to the higher mass of canola crop residue compared to the use of bean and the Ca contributions with this residue, since this is a nutrient with a moderate input through crop fertilization (261 kg ha^{-1} triple superphosphate providing 37 kg Ca). The inversely proportional effect of bean residue rate on Ca concentration in corn grain may be related to higher soil microbial activity compared to higher residue rate and the nutrient requirements of this biomass [8,33,34], in addition to the formation of organo-mineral complexes in soil aggregate formation[35].

Higher Ca and Mg concentrations in corn residue obtained after bean cultivation may be explained by higher soil biomass activity and its influence on soil nutrient cycles [8,10,34]. The effect of higher bean crop residue rate on lower residue Mg concentration was previously discussed and may be associated with higher biomass activity in soils with higher nutrient requirements [8,33,34].

The concentration of macronutrients and their ranking in corn grains and residue are consistent with the findings of several authors [28-30,36].

Nutrient extractions in corn grain were normal for the study area [30] and higher than several Northern Hemisphere edaphic conditions [28,29] and the extraction ranking concurs with several authors [28,29,36]. The directly proportional relationship between N and P extraction in corn grain and the rate of residue incorporation after canola cultivation can be explained by the higher nutrient input associated with the incorporated residue. Meanwhile, the inversely proportional relationship between Ca extraction in grain and increased residue rate in bean could be due to the higher nutrient requirement of soil biomass when a higher residue rate is added [34,37,38] and to the aggregate formation of Ca-organic complexes when residues are incorporated to facilitate the delivery of substrates to the soil microbial biomass [39]. Melo [37] indicated that the application of calcium and magnesium silicate and limestone positively influenced biomass and respiration rate in soil grown with *Bidens pilosa* L. and corn. The higher S extraction in corn grain after bean cultivation compared to canola may be due to the lower C:N ratio and polyphenol content of the bean residue and the higher S concentration in this crop, resulting in higher availability of this nutrient [33,40-43].

Nutrient extraction in the corn residue was normal for the study area [30] and the extraction ranking concurred with those indicated by several authors [28,29,36]. The higher Ca and Mg extraction in corn residue after bean cultivation contrasted with the lower Ca extraction by grain and the erratic effect for Mg; this indicates that Ca translocation and partial Mg translocation to grain are affected by the higher rate of bean residue. This could be explained by metabolic processes in the plant that affect nutrient translocation at the grain filling stage during the final third of crop development [28,36,44]; this was not assessed in the present study.

Regarding nutrient distribution in corn grain and other reports for cereal crops, the highest proportion of N, P, Mg, and S was concentrated in the grain [28,30,36,45] ,this is associated with the structural and metabolic functions of these nutrients, such as protein composition and enzyme cofactors [44]. The highest proportion of K and Ca was found in the aerial residue, which was also reported in other studies on cereals [28,30,36,45]. This greater accumulation of K and Ca in the aerial residue is associated with the structural functions of Ca in the rigidity of the stem (pectates, phosphates, and oxalates), plant vascular system and the reduced mobility of this nutrient towards carbohydrate accumulation structures such as grains. Other factors in the case of K are the functions of water status, osmotic potential, neutralization of soluble and insoluble macromolecular anions present in the aerial residue, lignification of vascular bundles and increased starch levels [44]. The lowest distribution coefficient of Ca and Mg in corn grain obtained after bean crop can be explained by the higher requirement of both nutrients by the microbial biomass [37] and the aggregate formation of Ca-organic complexes when residues are incorporated that facilitate the delivery of substrates to the soil microbial biomass [39].

Conclusions

The results indicated that grain yield and residue production were not affected by the preceding crop and residue incorporation rates. The preceding crop affected the concentration and extraction of some nutrients in both grain and residue. The residue incorporation rate affected both concentration and extraction of some nutrients in grain only. Extractions of S in grain and Ca and Mg in the residue was lower after canola. Ca extraction in grain was lower after bean cultivation. The Ca distribution in corn grain was negatively affected by the preceding bean crop and its higher residue incorporation rate. The ranking of total macronutrient extraction in the corn crop was K > N > Ca > P > Mg > S; mean extractions in the experiment ranged from 320.0 to 325.8, 56.0 to 57.1, 364.7 to 373.7, 86.5 to 99.3, 39.4 to 42.4, and 22.6 to 23.7 kg ha^{-1} for N, P, K, Ca, Mg, and S, respectively. Grain nutrient distribution coefficients ranged from 64.5 to 66.8, 90.1 to 90.9, 23.1 to 23.7, 1.3 to 2.0, 50.8 to 57.5, and 60.3 to 60.6 for N, P, K, Ca, Mg, and S, respectively.

Acknowledgments

We express our sincere thanks to the Chilean Agricultural Research Institute (INIA) for funding this experiment and contributing to the continuation of this line of research in the long term.

References

1. Oas S, Adams K. The Nutritional Content of Five Southwestern US Indigenous Corn (*Zea mays* L.) Landraces of Varying Endosperm Type. 2022 https://doi.org/10.1017/aaq.2021.131 Published online by Cambridge University Press.
2. 35. Statista. https://es.statista.com/estadisticas/1130624/superficie-maiz-cultivada-en-el-mundo/ consultado el 19 de enero de 2021.
3. ODEPA. Boletín del maíz. In Merino T, García A (eds.). 2016;20 p. Available at https://www.odepa.gob.cl/wp-content/uploads/2016/08/Boletinmaiz201607-1.pdf
4. Wingeyer AB, Walters DT, Drijber RA, Olk DC, Arkebauer TJ, Verma SB. Fall conservation deep tillage stabilizes corn residues into soil organic matter. *Soil Sci. Soc. Am. J.* 2012;76:2154-2163. Doi:10.2136/sssaj2012.0121
5. Hirzel J, Matus I, Novoa F, Walter I. Effect of poultry litter on silage corn (Zea mays L.) production and nutrient uptake. *Spain J. Agric. Res.* 2007;5:102-109.
6. . Hirzel J, Undurraga P, León L, Panichini M, González J, Carrasco J, Matus I. Corn grain production, plant nutrient concentration and soil chemical properties in response to different residue levels from two previous crops. *Acta Agric. Scandinavica.* 2020. DOI: 10.1080/09064710.2020.1725619.
7. Sommer R, Wall PC, Govaerts B. Model-based assesment of corn cropping under conventional and conservation agricultura in Highland Mexico. *Soil Till. Res.* 2007;94:83-100.
8. Kumar M, Kundu DK, Ghorai AK, Mitra S, Singh SR. Carbon and nitrogen mineralization kinetics as influenced by diversified cropping systems and residue incorporation in Inceptisols of Eastern Indo-Gangetic Plain. *Soil Till. Res.* 2018;178:108-117.
9. Sfez S, De.Meester S, Dewulf J. Co-digestion of rice straw and cow dung to supply cooking fuel and fertilizers in rural India: Impact on human health, resource flows and climate change. *Sci. Total Environ.* 2017;609:1600-1615.
10. Basir A, Jan MT, Alam M, Shah AS, Afridi K, Adnan M, Ali K, Mian IA. Impacts of tillage, stubble management, and nitrogen on wheat production and soil properties. *Can. J. Soil Sci.* 2016;97:133-140.
11. Stewart C, Roosendaal D, Manter D, Delgado J, Del Grosso S. Interactions of stover and nitrogen management on soil microbial community and labile carbon under irrigated no-till corn. *Soil Sci. Soc. Am. J.* 2018;82:323-331.
12. Urra J, Mijangos I, Lanzén A, Lloveras J, Garbisu C. Effects of corn stover management on soil quality. Europ. J. Soil Biol. 2018;88:57-64.
13. Limon-Ortega A, Govaerts B, Sayre KD. Straw management, crop rotation, and nitrogen source effect on wheat grain yield and nitrogen use efficiency. *Eur. J. Agron.* 2008;29:21-28.
14. Kazemeini SA, Bahrani MJ, Pirasteh-Anosheh H, Mehdi SM. Corn growth and yield as affected by wheat residues and irrigation management in a no-tillage system. *Archives Agron. Soil Sci.* 2014;60:1543-1552.
15. Pandiaraj T, Selvaraj S, Ramu N. Effects of crop residue management and nitrogen fertilizer on soil nitrogen and carbon content and productivity of wheat (*Tritucum aestivum* L.) in two cropping systems. *J. Agr. Sci. Tech.* 2015;17:249-260.
16. Chen X, Mao A, Zhang Y, Zhang L, Chang J, Gao H, Thompson ML. Carbon and nitrogen forms in soil organic matter influenced by incorporated wheat and corn residues. *Soil Sci. Plant Nut.* 2017;63:377-387.
17. Zhang L, Wang J, Fu G, Zhao Y. Rotary tillage in rotation with plowing tillage improves soil properties and crop yield in a wheat-corn cropping system. PLOS ONE 2018;13(6):e0198193. https://doi.org/10.1371/journal.pone.0198193.
18. Zhao HL, Jiang YH, Ning P, Liu JF, Zheng W, Tian X, Shi J, Xu M, Liang Z, Sharand AG. Effect of different straw return modes on soil bacterial community, enzyme activities and organic carbon fractions. *Soil Sci. Soc. Am. J.* 2019;83:638-648. doi:10.2136/sssaj2018.03.0101.
19. Govaerts B, Sayre KD, Deckers J. Stable high yields with zero tillage and permanent bed planting? *Field Crops Res.* 2005;94:33-42.
20. Hirzel J, Retamal-Salgado J, Walter I, Matus I. Residual effect of cadmium applications in different crop rotations and environments on durum wheat cadmium accumulation. *J. Soil Water Conservation* 2019;74:42-51.
21. Chen Z, Wang Q, Wang H, Bao L, Zhou L. Crop yields and soil organic carbon fractions as influenced by straw incorporation in a rice-wheat cropping system in southeastern China. *Nutr. Cycl. Agroecosyst.* 2018;112:61-73.

22. Swanepoel PA, le Roux PJG, Agenbag GA, Strauss JA, MacLaren C. Seed-drill opener type and crop residue load affect canola establishment, but only residue load affects yield. *Agron J.* 2019;111:1658-1665 doi:10.2134/agronj2018.10.0695.
23. United States Department of Agriculture (USDA). Keys to soil taxonomy (12th ed.) Washington D.C.: USDA. 2014.
24. Sadzawka A, Carrasco MA, Demanet R, Flores H, Grez R, Mora ML. Métodos de análisis de tejidos vegetales. Serie Actas INIA N°40. 2007;140 p. 2ª ed. Instituto de Investigaciones Agropecuarias (INIA), Santiago, Chile.
25. SAS Institute. Usage and reference. Version 6. 1989;501 p. Cary, NC: SAS Institute.
26. Retamal-Salgado J, Hirzel J, Walter I, Matus I. Bioabsorption and bioaccumulation of cadmium in the straw and grain of corn (*Zea mays* L.) in growing soils contaminated with cadmium in different environment. *Int. J. Environ. Res. Public. Health* 2017;14:1399. doi:10.3390/ijerph14111399.
27. Lawrence PA, Radford BJ, Thomas GA, Sinclair DP, Key AJ. Effects of tillage practices on wheat performance in a semi-arid environment. *Soil Till. Res.* 1994;28:347-364.
28. Woli KP, Sawyer JE, Boyer MJ, Abendroth LJ, Elmore RW. Corn era hybrid macronutrient and dry matter accumulation in plant components. *Agron. J.* 2018;110:1648-1658. DOI:10.2134/agronj2018.01.0025
29. Overmann AR, Scholtz RV. Accumulation of biomass and mineral elements with calendar time by corn: application of the expanded growth model. PLOS ONE 2011;6:e28515. DOI:10.1371/journal.pone.0028515.t001.
30. Hirzel J. Fertilización de cultivos en Chile segunda edición aumentada y corregida. Libro INIA N°44, 2021;568 p. Instituto de Investigaciones Agropecuarias. Chillán. Chile.
31. Sallaku G, Liko J, Rada Z, Balliu A. The effects of legume crops (pea and faba bean) on soil nutrients availability and yield parameters of subsequent cabbage crops under organic production conditions. *J. Environ. Sci. Engineering*. 2016;5:619-625.
32. Plaza-Bonilla D, Nogué-Serra I, Raffaillac D, Cantero-Martínez C, Justes É. Carbon footprint of cropping systems with grain legumes and cover crops: A case-study in SW France. *Agric. System* 2018;167:92-102.
33. Truong THH, Marschner P. Amendment with high and low C/N residues- Influence of rate, order and frequency. *J. Soil Sci. Plant Nut.* 2018;18:705-720.
34. McDaniel MD, Grandy AS, Tiemann LK, Weintrau MN. Crop rotation complexity regulates the decomposition of high and low quality residues. *Soil Biol. Biochem.* 2014;78:243-254.
35. Neall VE. Volcanic soils. Encyclopedia of Life Support Systems (EOLSS). Land use and land cover VII: 2006;1-24. Available at http://www.eolss.net/ebooks/Sample%20Chapters/C19/E1-05-07-13.pdf (accessed January 2021)
36. Echeverría HE, Sainz Rozas H, Barbieri PA. Maíz y Sorgo. 2014; Pág. 435-478. In: Fertilidad de Suelos y Fertilización de Cultivos. Segunda Edición. Echeverría HE, Garcia FO(eds). 904 p. Ediciones INTA.
37. Melo C, Fialho C, Faria A, Neto M, Saraiva D, Costa M, Ferreira L, Ferreira FA. Microbial activity of soil cultivated with corn in association with weeds under different fertility management systems. *Chilean J. Agric. Res.* 2014;74:477-484.
38. Kerdraon L, Balesdent M, Barret M, Laval V, Suffert F. Crop residues in 438 wheat-oilseed rape rotation system: a pivotal, shifting platform for microbial 439 meetings. *Microbial Ecol.* 2019;77:931-945.
39. Baldock JA. Influence of Calcium on the decomposition of organic material in soils. Thesis submitted for the degree of Doctor of Philosophy. Department of Soil Science. The Waite Agricultural Research Institute. The University of Adelaide. 1989;142 p.
40. Bell JM. Factors affecting the nutritional value of canola meal: A review. *Can. J. Anim. Sci.* 1993;73:679-697.
41. Heard J, Hay D. Nutrient content, uptake pattern and carbon:nitrogen ratios of prairie crops. Manitoba Agriculture, Food and Rural Initiatives, Carman, Canada. 2006.
42. Németh T, Máthé-Gáspár G, Radimszky L, Gyiri Z. Effect of nitrogen fertilizer on the nitrogen, sulphur and carbon contents of canola (*Brassica napus* L.) grown on a calcareous Chernozem soil. *Cereal Res. Com.* 2007;837-840. doi:10.1556/CRC.35.2007.2.168.
43. Akond GM, Khandaker L, Berthold J, Gates L, Peters K, Delong H, Hossain K. Anthocyanin, total polyphenols and antioxidant activity of common bean. *Am. J. Food Tech.* 2011;6:385-394. DOI: 10.3923/ajft.2011.385.394.
44. Marschner P (ed.). Marschner's Mineral nutrition of higher plants. 3rd ed. Academic Press, London, UK. 2012;651 p.
45. Ahmed A, Aftab S, Hussain S, Nazir Cheema H, Liu W, Yang F, Yang W. Nutrient Accumulation

and Distribution Assessment in Response to Potassium Application under Corn–Soybean Intercropping System. *Agron.* 2020;10:725. DOI:10.3390/agronomy10050725.