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Research Article

Is Strip Cropping an Effective Way for Maize Biofortyfication?

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The aim of the study was to assess the impact of strip cropping on the content of nitrogen, phosphorus, potassium, magnesium, and calcium in maize. A field experiment was conducted during 2008–2010 in South Poland. The two cropping methods of maize were studied: sole cropping and strip cropping with common bean and spring barley. Maize was harvested in two different cycle stages: for silage in milky-wax phase and for grain in full maturity phase. Strip cropping significantly increased the accumulation of Mg and Ca by maize biomass and grain. However, the phosphorus content was higher only in maize grain. The row position in the strip influenced the macronutrients content in maize biomass and in grain. The placement adjacent to the bean resulted in higher Ca and Mg content in maize biomass and in grain. The phosphorus content in maize grain was also significantly higher in neighbouring rows with common bean strip. The least amounts of P and N were found in maize from the row adjacent to the barley strip. The results obtained indicated that strip cropping of maize with appropriate plant species, especially pulses, that is, common bean, seems to be an effective way to biofortify maize grain with Ca, especially in regions where it is the staple food. Furthermore, this may mitigate the deficiency of Mg and Ca in maize forage.

1. Introduction

Crop plants composition and nutritional value are very important to the health of humans and animals [1]. However, it was estimated that a considerable proportion of people worldwide suffer from deficiencies of mineral components such as Fe, Zn, Cu, Ca, and Mg. Traditional strategies to deliver these nutrients have relied mainly on mineral supplementation, dietary diversification, and food fortification [2]. An alternative complimentary solution to mineral malnutrition is "biofortification." Biofortification has been defined as the process of increasing the bioavailable concentrations of essential elements in edible portions of crop plants through agronomic intervention or genetic selection [3–5]. The concept of biofortification is attractive not only for improving the growing conditions of crops but also for exploiting a plant's potential for nutrient mobilization and utilization. In addition to mineral fertilization, conventional breeding, and transgenic plants, intercropping between dicots and gramineous species would be the key to biofortification of some staple crops.

Intercropping systems involve two or more crop species or genotypes growing together and coexisting for a time. Compared with monocrops, they are reported to deliver pest control, similar yields with reduced inputs, pollution mitigation, and greater or more stable aggregate food or forage yields per unit area [5, 6]. Strip cropping can be regarded as an adaptation of the more traditional intercropping systems, but one which allows the use of modern farm machinery. The selection of plants with different developmental cycles and morphological structures enables more efficient utilization of nutrients, water, and light in strip cropping than in sole cropping. Moreover, interaction between species in the rhizosphere can affect nutrient availability and uptake [7–9].

Thus, the objectives of the present work were to evaluate the impact of strip cropping and time of harvest on the uptake of macronutrients by maize.

2. Materials and Methods

Investigations were conducted during 2008–2010 at the experimental station of the Faculty of Agricultural Sciences, University of Life Sciences in Lublin (50°42′N, 23°16′E). The soil was brown soil of the group Cambisols (WRB 2007), slightly acidic (pH in 1 M KCL 6.2), with organic matter content of 19 g·kg^{-1} (according to Tiurin), high content of available P (185 mg·kg^{-1}) and K (216 mg·kg^{-1}), and average content of Mg (57 mg·kg^{-1}). The content of phosphorus and potassium in the soil was determined by the Egner–Riehm method, after extraction with calcium lactate. The magnesium content was determined using atomic absorption spectrometry after extracting from the soil with $CaCl_2$ solution. For these extraction methods, refer to the limit numbers defining the degree of soil richness in P, K, and Mg used in Chemical and Agricultural Stations in Poland. The experiment employed a split-plot design with 4 replications. The two cropping methods of maize were analysed: sole cropping and strip cropping with common bean and spring barley (Figure 1). Maize was harvested in two different cycle stages: milky-wax phase for silage, BBCH 79/83, and full maturity phase for grains, BBCH 99.

In sole cropping, the size of one plot area was 26.0 m^2, with 10 rows of maize per plot, and spacing between rows at 65 cm. In strip cropping, maize was grown in adjacent strips of 3.3 m wide, with 5 rows of maize planted in each strip, spaced at 65 cm. The one plot area for maize was 11.75 m^2. In the successive years, maize was sown on 28 April, and 2 and 5 May. The seeding rate was 100,000 seeds per hectare. Maize for silage was harvested on 30 August 2008, 5 September 2009, and 9 September 2010. Maize for grain was harvested on 15, 11, and 13 October. Bean was grown for dry seeds and was sown in the same time as maize and was harvested on 19 August 2008, 16 August 2009, and 3 September 2010. Spring barley was sown on 12, 15, and 19 April, and harvested on 2, 6, and 12 August (BBCH 89). Maize mineral fertilization was applied uniformly at the rates of N 140, P 35, and K 100 kg·ha^{-1} (N, ammonium nitrate; P, triple superphosphate; K, potassium salt). Phosphorus and potassium fertilizers were applied once before spring presowing treatments and nitrogen was applied in split applications (half before sowing and the remainder for top dressing in the 4-5 leaf stage, BBCH 14/15). The doses of fertilizer components were determined on the basis of soil richness and maize needs. Chemical weed regulations in maize were applied uniformly—herbicides: a.i. bromoxynil + terbuthylazine at 144 g·ha^{-1} + 400 g·ha^{-1} at the 4–6 leaf stage, BBCH 14/16.

Weather conditions during the study are presented in Table 1. Rainfall was lowest in the second year of the experiment and was lower than the long-term average. Moreover, rainfall was unevenly distributed over the year. A severe shortage occurred in April and July, while heavy precipitation was recorded in May and June. In the first and third years of the study, rainfall was much higher and exceeded the long-term average by 56.4–61.8 mm. Average monthly temperatures for each year were higher than the long-term average. The year 2010 was particularly warm; the temperature sum (calculated as the sum of the products of the average temperature and the number of days in the month) in the months of April–September was 3,141°C. On the basis of Selyaninov's hydrothermal coefficient, the 2008 and 2010 growing seasons were classified as optimal, while the 2009 season was rather dry. In 2009, dry months, in particular, were April and July.

Prior to harvest in both seasons, three maize plants were collected from the middle rows of each plot. From each strip cropping plot three plants were collected from the border rows adjacent to the bean and barley strips, as well as from the middle row. The macronutrients content in maize biomass and grain was determined by the following methods: nitrogen (N) by Kjeldahl digestion, phosphorus (P) by spectrophotometry, potassium (K) and calcium (Ca) by flame photometry, and magnesium (Mg) by flame atomic absorption spectrometry (FAAS). The content of P, K, Ca, and Mg was determined after wet mineralization of samples in a mixture of nitric and perchloric acids. The analyses were performed at the Regional Chemical and Agricultural Station in Lublin, in accordance with the standard analytical procedures. The results were converted to dry weight. The mean content of macroelements for the strip was calculated as weighted averages for the inner row and two border rows. When calculating the means, the content of the element and the yield of biomass or maize grains from individual rows were taken into account.

The results were analysed statistically by ANOVA using STATISTICA PL (Tulsa, USA). Differences between averages were determined using Tukey's test with $P < 0.05$.

3. Results and Discussion

The yield of maize biomass and grain was the lowest in 2009. The yield of maize biomass in the strip cropping was on average 10.7% higher than in the sole cropping (Table 2). This resulted from a significant increase in yield in the maize border row—26.8% in the row adjacent to the common bean and 17.3% in the row next to barley.

The grain yield was also higher in strip cropping, on average for the period of research, by 14% in comparison with sole cropping. The increase in maize yield is due to its strong response to the edge effect [10] and efficient utilization of sunlight. Light interception has been observed to be highest in the border rows in strip intercropping of maize/soybean/oat [11] and maize/pea [12]. The mechanism behind that phenomenon may also be related to the corresponding below-ground root length growth and distribution advantages at later growth stages of the maize after the intercropped plants have been harvested [13].

In each year of research, as well as on average for experiment, the nitrogen and potassium content were significantly lower in the biomass of the maize grown in strip cropping than that grown in sole cropping. The

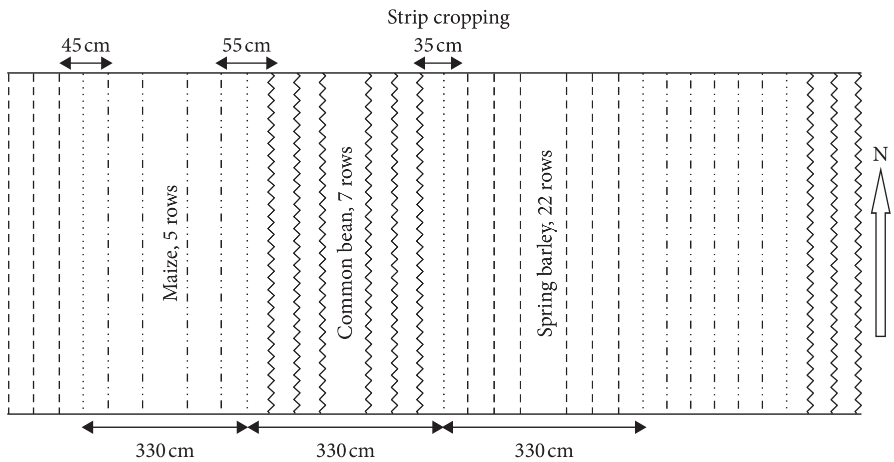

Figure 1: Row arrangements of maize, common bean, and spring barley in strip cropping. The row spacing of maize was 65 cm, while that of common bean was 47 cm, and that of spring barley was 15 cm. N, north.

Table 1: Rainfall and air temperature in months IV–IX as compared to the long-term means (1971–2005), according to the Meteorological Station in Zamość.

Years	IV	V	VI	VII	VIII	IX	Sum/mean IV–IX
Rainfall (mm), p							
2008	71.5	74.8	48.9	104.6	69.7	80.4	449.9
2009	15.5	102.6	124.4	24.2	48.9	34.5	350.1
2010	30.7	106.7	62.9	143.5	86.1	25.4	455.3
Means for 1971–2005	44.1	65.5	78.9	98.4	54.3	52.2	393.5
Temperature (°C), T							
2008	10.7	15.5	19.4	20.2	20.6	19.7	3031
2009	11.3	13.8	20.2	20.0	20.1	16.9	3122
2010	11.0	15.1	18.4	21.5	20.2	16.6	3141
Means for 1971–2005	7.9	14.1	16.8	18.4	17.8	12.9	2690
Selyaninov's coefficient, k							
2008	2.23	1.56	0.84	1.67	1.09	1.36	1.48
2009	0.46	2.40	2.05	0.39	0.78	0.68	1.12
2010	0.93	2.31	1.14	2.15	1.37	0.51	1.45
Means for 1971–2005	1.86	1.50	1.57	1.73	0.98	1.35	1.46

k, Selyaninov's coefficient $[k = (p \times 10)/\sum t]$.

Table 2: Effect of cropping and row position in the strip on maize yield in $t \cdot ha^{-1}$ DM.

Phase of harvest	Year	Strip cropping: Row in the strip: Next to barley	Inner	Next to bean	Mean for strip	Sole cropping
Biomass for silage	2008	20.70b	18.90a	23.40c	20.60B	18.60A
	2009	19.30b	17.10a	20.20b	18.40B	16.60A
	2010	22.10b	16.77a	23.60c	19.70B	17.80A
	Mean	20.69*b*	17.59*a*	22.40*c*	19.60*B*	17.70*A*
Grain	2008	6.40b	5.90a	8.04c	6.75B	5.80A
	2009	5.40a	5.10a	6.72b	5.73B	5.10A
	2010	5.90b	5.41a	7.23c	6.15B	5.60A
	Mean	5.90*b*	5.47*a*	7.30*c*	6.22*B*	5.50*A*

Values with different letters in line differ significantly ($P = 0.05$); capital letters: cropping method; small letters: row position in the strip.

lower content of nitrogen and potassium resulted from the reduction in their content in the edge rows of the maize strip, particularly the one adjacent to barley (Table 3).

Strip cropping significantly increased the content of nitrogen in maize grain. This was particularly evident in the row adjacent to the bean strip (Table 4). Differences between the potassium content in the grain were insignificant. Barley

Table 3: Effect of cropping method and row position in the strip on macronutrients content in the maize biomass harvested for silage ($g \cdot kg^{-1}$).

Nutrients	Years	Strip cropping: Row in the strip: Next to barley	Inner	Next to bean	Mean for strip	Sole cropping
Nitrogen	2008	10.60a	13.91c	12.41b	12.26A	13.02B
	2009	12.31a	15.78c	14.56b	14.17A	14.91B
	2010	11.50a	15.07c	13.95b	13.38A	14.19B
	Mean	11.47*a*	14.92*c*	13.64*b*	13.27*A*	14.04*B*
Phosphorus	2008	1.95a	2.35b	2.38b	2.23A	2.65B
	2009	1.82a	2.14b	2.26c	2.08A	2.46B
	2010	2.23a	2.41b	2.56c	2.41A	2.75B
	Mean	2.00*a*	2.30*b*	2.40*b*	2.24*A*	2.62*B*
Potassium	2008	7.52b	8.41c	7.24a	7.68A	9.16B
	2009	8.89a	9.82b	8.93a	9.19A	10.98B
	2010	8.49b	9.67c	8.13a	8.67A	10.64B
	Mean	8.30*a*	9.30*b*	8.10a	8.57*A*	10.26*B*
Magnesium	2008	0.80a	1.01b	1.02b	0.94B	0.83A
	2009	0.77a	0.93b	0.94b	0.88B	0.74A
	2010	0.83a	1.06b	1.04b	0.96B	0.86A
	Mean	0.80*a*	1.00*b*	1.00*b*	0.93*B*	0.81*A*
Calcium	2008	2.41a	2.81b	3.18c	2.81B	2.40A
	2009	2.34a	2.73b	2.83b	2.64B	2.03A
	2010	2.45a	2.86b	3.29c	2.88A	2.35A
	Mean	2.40*a*	2.80*b*	3.10*c*	2.79*B*	2.26*A*

Values with different letters in line differ significantly ($P = 0.05$); capital letters: cropping method; small letters: row position in the strip.

Table 4: Effect of cropping method and row position in the strip on macronutrients content in maize grain ($g \cdot kg^{-1}$ d.m.).

Nutrients	Years	Strip cropping: Row in the strip: Next to barley	Inner	Next to bean	Mean for strip	Sole cropping
Nitrogen	2008	17.82b	17.06a	18.77c	17.98B	17.03A
	2009	18.56a	18.41a	20.21b	19.76B	18.65A
	2010	18.46b	18.02a	19.94c	18.91B	18.26A
	Mean	18.28*b*	17.83*a*	19.64*c*	18.88*B*	17.98*A*
Phosphorus	2008	3.96b	3.29a	4.19c	3.86B	3.15A
	2009	3.25b	2.97a	3.72c	3.46B	2.63A
	2010	4.10b	3.76a	4.36c	4.10B	3.25A
	Mean	3.77*b*	3.34*a*	4.09*c*	3.81*B*	3.01*A*
Potassium	2008	6.93b	6.51a	7.48c	7.03A	6.57A
	2009	7.24a	6.95a	7.72b	7.57A	7.09A
	2010	7.37a	7.09a	7.93b	7.51A	7.28A
	Mean	7.18*a*	6.85*a*	7.71*b*	7.37*A*	6.98*A*
Magnesium	2008	1.79a	1.87a	2.13b	1.94B	1.52A
	2009	1.93a	2.05a	2.27b	2.17B	1.83A
	2010	1.92a	1.96a	2.35b	2.10B	1.75A
	Mean	1.88*a*	1.96*a*	2.25*b*	2.07*B*	1.70*A*
Calcium	2008	0.84a	1.03b	1.21c	1.04B	0.53A
	2009	0.91a	1.14b	1.44c	1.23B	0.69A
	2010	0.95a	1.19b	1.46c	1.22B	0.65A
	Mean	0.90*a*	1.12*b*	1.37*c*	1.16*B*	0.62*A*

Values with different letters in line differ significantly ($P = 0.05$); capital letters: cropping method; small letters: row position in the strip.

was sown 3 weeks earlier than maize, and may have been more competitive with the maize plants, especially in the early growth stages. Gerry and Wilson [14] reported that the initial size of the plant may influence the competitive ability of species in intercropping, although Cruse [15] believes that competition between maize and cereals in strip cropping should be minimized, as these plants have different cycles of development and their maximum demand for water and minerals occurs at different times. According to Cakmak [16], the nitrogen content in plants decreases with increased yield, because plants are not able to take up enough nutrients. Therefore, the changes in nitrogen and potassium content in the maize biomass found in the present study may be due to the higher maize yield in strip cropping, especially in the edge rows of the strip. This is confirmed by the higher nitrogen and potassium uptake in the rows adjacent to the beans. Ghaffarzadeh et al. [17] also argue that differences in maize yield in individual rows in the strip can affect the demand for N in plants; thus, additional N fertilizer should be applied to the edge rows, in order to realize their potential for higher yield.

In the present study, the highest nitrogen uptake by maize biomass, as well as by grain, was noted in the edge row next to bean (Figures 2 and 3). Similarly, Głowacka [18] reported the highest N uptake by maize in the edge row of the strip next to the lupin. This may result from the transfer of nitrogen to maize from bean, which has been observed in a number of legumes/cereal intercropping [19]. Although, according to Temperton et al. [20], the main driving force behind the facilitative interactions between N-fixing and non-N-fixing species is N sparing, i.e., reduced competition for soil N, with N transfers playing a secondary role. Furthermore, the interactions between N-fixers and non-N-fixers are species specific and change according to the capacity of the receiver species to use N provided by the legume [21].

According to Inal et al. [22] improvement in soil acid phosphatase activity in rhizosphere might be responsible for increased phosphorus nutrition to plants in intercropping. In the present study, the content of phosphorus in the maize biomass in sole cropping and in strip cropping was similar (Table 3), but strip cropping significantly increased the phosphorus content in maize grain (Table 4). In part, it can be related to the fact that the intensive uptake of phosphorus by maize begins before flowering and gradually increases until ripening. So, it is in the period after the harvest of barley and beans in adjacent strips. Li et al. [23] reported that faba bean and maize intercropping facilitated phosphorus nutrition in maize. They observed that phosphorus concentration was higher in the intercropped maize than in the sole cropping plants but only during the grain filling to mature stages of maize. The improved phosphorus nutrition in maize in intercropping could have resulted from an increased uptake of P released during the decomposition of root residues of the faba bean. It was evident that P concentration and uptake in maize were increased mainly by intercropping at later growing stages after the faba bean had been harvested [23].

There is another probable explanation for this phenomenon. It was shown that faba bean, as a legume, was better nodulated when intercropped than in monoculture and may have fixed more atmospheric N and take up more cations than anions and release H+ from the roots. Therefore, the increase in N fixation in intercropped leguminous plants may have led to increased proton excretion by legumes, and this may have contributed to the mobilization of sparingly soluble phosphate in the rhizosphere and thus improved P nutrition in intercropped species [22–24]. Similar facilitation in P nutrition has been found by Ae et al. [25] in sorghum/pigeon pea intercropping. Pigeon pea increased phosphorus uptake of the intercropped sorghum by exuding piscidic acid that chelates Fe^{3+} and subsequently releases phosphorus from $FePO_4$.

In strip cropping, significant higher phosphorus uptake by maize biomass and by maize grain was observed in the row adjacent to bean (Figures 2 and 3). Leguminous plants have the ability to recover phosphorus from unavailable forms [26]. One mechanism is the secretion of organic acids which reduce the pH of the rhizosphere and release P from unavailable compounds. Bean mainly secretes citrates [27], while lupins and faba beans mainly secrete malate [28]. Li et al. [29] reported that chickpea contributes to higher content of phosphorus in maize/wheat intercropping. This may result from the release of carboxylates by the roots, which improve the solubility of phosphorus in the rhizosphere and increase its acquisition. According to Chen [30], the increase in phosphatase activity is accompanied by an increase in the release of phosphates from organic phosphorus compounds.

Species can facilitate each other by creating the habitat and/or increasing nutrient availability for co-occurring species [31]. Li et al. [24] showed that intercropping of wheat and chickpea increased the uptake of Ca and Mg by crop plants, and this better nutrient use was due to rhizosphere acidification. In addition, wheat produced four times more roots than chickpea and hence was more competitive to nutrient uptake. In our study, strip cropping also led to higher content of Mg and Ca in maize than sole cropping. The placement next to the bean resulted in higher content of Ca and Mg in the maize biomass and grain (Tables 3 and 4). This is consistent with the results obtained by Głowacka [18] regarding changes in the content of Ca and Mg in maize strip cropped with lupin and oats. Some plants can release greater amounts of carboxylates through their roots, which may increase utilization of Ca by coexisting plants, even from less available compounds [32]. On the other hand, legumes have a well-developed root system and may take up nutrients, that is, P, K, Mg, and Ca, in the deeper layers and move them into the soil profile, making them available to other plants [25]. Magnesium and calcium acquisition by maize intercropped with barley and common bean was significantly increased when compared with sole maize. The macronutrient accumulation by maize in the border rows, especially in the row next to bean, was significantly greater than in the inner row (Figures 2 and 3). This relationship was seen regardless of the time of maize harvest.

Maize is widely used as food for humans and as feed for animals. According to Zamora and De Regil [33] more than 200 million people rely on maize, in any of its forms, as a staple food, especially in WHO regions such as African region, region of Americas, or Southeast Asian region [34]. Maize consumption in the African WHO region ranges from 52 (in Uganda) to 328 (in Lesotho) g/person/day, whereas in the region of the Americas was the highest in Mexico (267 g/person/day) [34, 35]. Table 5 presents the estimated coverage of the demand for macroelements at various levels of maize consumption by people in different regions of the world. Taking into account the recommended daily allowance (according to WHO) for macroelements, such as P, Mg, and Ca and the average daily consumption of maize in

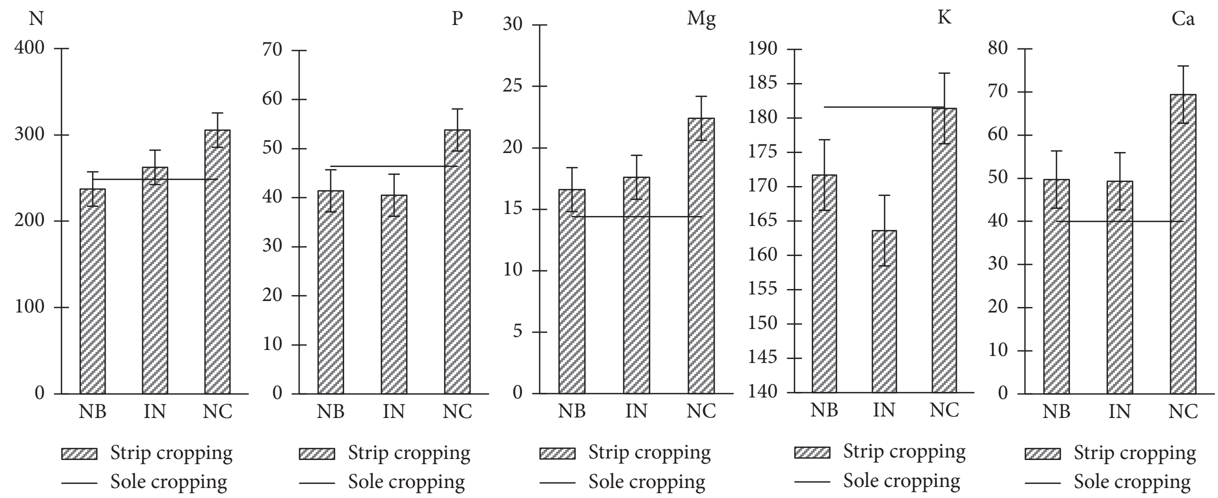

Figure 2: The influence of cropping method and row position in the strip on macronutrients uptake by maize biomass (in kg·ha^{-1}) (mean for 2008–2010). NB, row next to barley; IN, inner row; NC, row next to common bean.

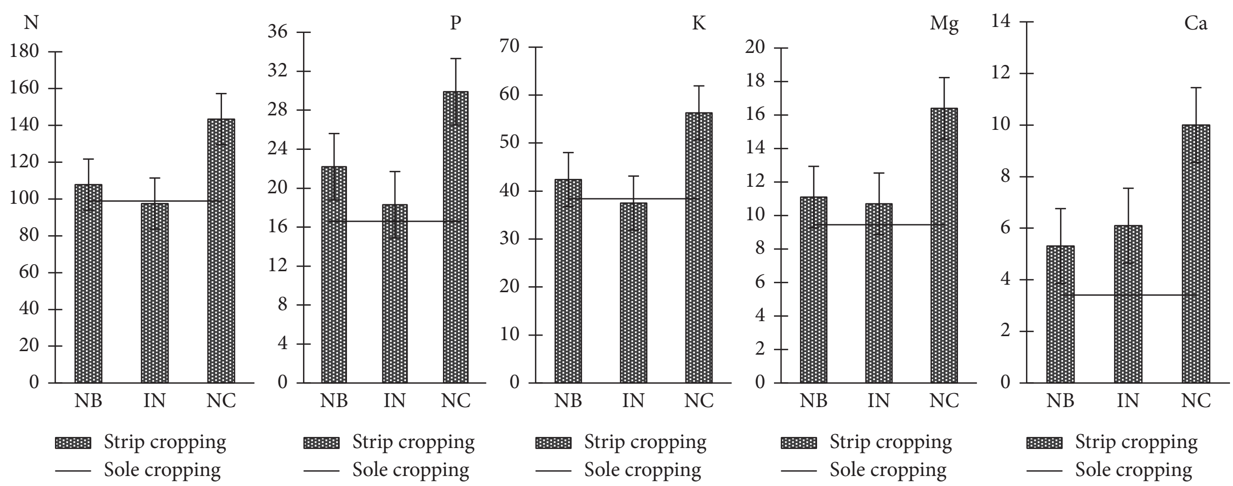

Figure 3: The influence of cropping method and row position in the strip on macronutrients uptake by maize grain (in kg·ha^{-1}) (mean for 2008–2010). NB, row next to barley; IN, inner row; NC, row next to common bean.

Table 5: The amount of nutrients supplied by maize grain at different levels of human consumption (in g) and the percentage coverage of the demand for these nutrients.

Element	RDA (g)[1]	Maize consumption (g person^{-1} day^{-1})[2]							
		52				328			
		Sole cropping		Strip cropping		Sole cropping		Strip cropping	
		(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
P	0.74–0.79	0.15	19.5	0.19	25.7	0.99	128.6	1.25	162.3
Mg	0.28–0.33	0.09	31.0	0.10	34.5	0.56	193.1	0.68	234.5
Ca	1.0–1.03	0.03	3.00	0.06	6.00	0.20	20.0	0.38	38.0

[1]Recommended daily allowance for adult people according to WHO [36]. [2]The lowest and highest consumption of maize in countries where it is a staple food [34, 35].

various countries, it can be concluded that strip cropping allows for a 50% increase in the amount of Ca in the diet of people. This can be important in countries with a high maize consumption, of around 320 g/day, as it increases the coverage of daily Ca demand from 20% to 38% (Table 5). The use of maize grain from strip cropping in human nutrition may also increase the amount of Mg and P supplied with food, but to a much lesser extent.

Strip cropping increased the Ca and Mg content in the maize biomass, and thus the intake of these components by cows fed corn silage. In comparison with maize silage from sole cropping, the coverage of the daily requirement of Ca

Table 6: The amount of nutrients supplied by maize silage at a dose of 16 kg·d.m. (in g) and the percentage of covering the cow's demand for these elements.

Element	Daily demand[1]	Sole cropping		Strip cropping	
		(g)	(%)	(g)	(%)
P	57	41.8	73.5	35.8	62.9
Mg	28	12.9	46.3	14.9	53.1
Ca	105	36.2	34.5	44.6	42.5

[1]For a cow weighing 600 kg and producing approx. 20 kg of milk [37].

and Mg for cow was higher by 8% and 6.8%, respectively (Table 6). Generally, maize forage is low in Ca and Mg and in order to balance the ratio, it requires the addition of mineral mixtures.

4. Conclusion

The results of this study confirm the impact of strip cropping on the content of macronutrients in maize. Strip cropping resulted in higher content of Mg and Ca but did not affect the P content in the maize biomass harvested for silage. It was also observed that the nitrogen content was slightly reduced and K was markedly reduced in the maize biomass harvested for silage. In maize grain, strip cropping increased the content of all macronutrients, except the content of potassium. This was due to changes in the content of elements in the maize depending on the position of the row in the strip and on the adjacent plant species. In general, the placement next to the bean strip resulted in higher content of Ca, Mg, and P in the maize biomass and in higher content of all investigated nutrients in maize grain. Selection of the appropriate species for strip cropping may limit shortages of some nutrients in plants. Strip cropping, especially with leguminous plants, gives the possibility of effective maize grain biofortification with Ca. This can be used especially in regions where maize is a staple food. It is also a way to biofortify maize silage with Mg and Ca but to a much lesser extent.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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